GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 12/15/78

Project Title: In Support of Material Flow Characteristics (MFC) Model Study

Project No: E-24-686 Green Card Mine

Project Director: Dr. John A. White

Sponsor: Research Triangle Institute; Research Triangle Park, NC 27709

Agreement Period: From 10/2/78 Until ~~5/15/79~~ 5/31/80 (Period of Performance)

Type Agreement: Subcontract No. 2-44U-1683 (Under Prime Contract No. F33615-78-C-5139)

Amount: $46,009

Reports Required: Weekly Activity Reports; Meetings on Task 2; Preliminary Work Plans on Tasks 7 and 8; Feedback on Preliminary Work Plans for Tasks 6 and 9; Written Review of Task 2; Refined Work Plans for Tasks 7 and 8; Monthly Subtask Reports on Tasks 7 and 8; Monthly Cost-Schedule Status Reports on Tasks 7 and 8; Interim Technical Reports on Tasks 7 and 8; Final Technical Reports on Tasks 7 and 8

Sponsor Contact Person (s):

Technical Matters

(RTI Project Manager)
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(919) 541-6000

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(thru OCA)

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Office of Research Contracts
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P. O. Box 12194
Research Triangle Park, NC 27709

(919) 541-6000

Defense Priority Rating: DO-C9 under DMS Reg. 1

Assigned to: Industrial & Systems Engineering (School/Laboratory)

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- Division Chief (EES)
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- Project Code (GTRI)
- Other ______

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 8/14/81

Project Title: In Support of Material Flow Characteristics (MFC) Model Study

Project No: E-24-686

Project Director: Dr. John A. W hite

Sponsor: Research Triangle Institute; Research Triangle Park, N.C.

Effective Termination Date: 5/31/80

Clearance of Accounting Charges: 5/31/80

Grant/Contract Closeout Actions Remaining:

- x Final Invoice and Closing Documents
- _ Final Fiscal Report
- _ Final Report of Inventions
- x Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______________

Assigned to: Industrial & Systems Engineering (School/~~Laboratory~~)

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Other: ______________

F-24-236

April 10, 1980

Dr. David L. Kelly
Project Leader
ICAM MFC Program
Research Triangle Institute
Research Triangle Park, NC 27709

Dear Dave:

Per your earlier request, the following items are enclosed in support of our ICAM/MFC activities:

a) Report on a Preliminary Investigation of a Group Technology Cell Using Simulation

b) Report on Group Technology

c) Report on Material Requirements Planning Systems

d) Surveys of Conveyors, Racks, and AS/RS

e) Revised Budget by Month

f) Monthly Work Sheet for March

We performed a, b, and c in the Fall and Winter Quarters to gain insights into the interactions of GT/layout/material handling/material control. This was done to support Tasks 14, 15, and 16 and to prepare us for the execution of Task 17.

Task 13 is complete, except for the IDEF diagrams of the equipment included in the survey that are applicable to the sheet metal center. The IDEF diagrams will be completed during April. As you will note from our survey, there exists a large number of equipment types for which IDEF diagrams are required.

The revised budget reflects the actual <u>total</u> expenditures through March and the budgeted expenditures for April and May. Our efforts on Tasks 16 and 17 have been preparatory, as reflected in the enclosed report. We are awaiting additional specificity from you concerning the next step to take.

Given that we are to discontinue our efforts on Task 17, my plan is to continue working on Tasks 13, 14, 15, and 16. If you have other preferences, please let me know.

I hope the information I've provided is helpful to you and answers the questions you raised in earlier correspondence.

Sincerely,

John A. White, Ph.D. ✓
Professor

JAW:vld

Enclosures (6)

cc: Dr. M. E. Thomas

EQUIPMENT KEY

I. Conveyors

1. Belt
2. Roller
3. Wheel
4. Slat
5. Magnetic Belt
6. Trolley
7. Power and Free
8. Transfer Tables
9. Palletizer/Depalletizer
10. Tow-line
11. Gravity Chute
12. Sortation

II. Robots

III. Containers and Supporting Equipment

1. Bins and Tote Boxes
2. Flow Racks
3. Shelving
4. Modular Drawers

IV. Storage and Retrieval

1. Stacker Crane
2. Unit Load AS/RS
3. Deep Lane AS/RS
4. Man-on-Board AS/RS
5. Mini Load AS/RS
6. Carousels

SHEET METAL SIZE CATEGORIES

Designation	J. White Category	Handling Unit	Length	Width
0	1, 2	part	(0, 1']	(0, 0.5']
A	1, 2, 3	tote	(0, 2']	(0, 2']
B	4	pallet	(2', 4']	(0.5', -)
C	5	strip	(2', 4']	(0, 0.5']
D	6	large pallet	(4', 8']	(1', -)
E	7	strip	(4', 8']	(0, 1']
F	8	flat	(8', 12']	(1.5', -)
G	9	strip	(8', 12']	(0, 1.5']
H	10	flat	(12', -)	(2', -)
I	11	strip	(12', -)	(0, 2']

Designation 0 is used for the handling of individual, small sheet metal parts on belt and slat conveyors.

MF ACTION PARAMETER: LOAD MATERIAL

EQPT KEY		SHEET METAL SIZE CATEGORIES									
		0	A	B	C	D	E	F	G	H	I
I	1	+,0	+,0	0	+,0	0	0	0	0	0	0
	2	NA	+,0	0	+,0	0	0	0	0	0	0
	3	NA	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	4	+,0	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	5	+,0	NA	NA	+,0	NA	NA	NA	NA	NA	NA
	6	NA	+,0	NA	+,0	NA	0	NA	NA	NA	NA
	7	NA	+,0	NA	+,0	NA	0	NA	NA	NA	NA
	8	NA	+,0	0	+,0	0	0	0	0	NA	NA
	9	NA	0	NA	0	NA	0	0	0	0	0
	10	NA	+	0	+,0	0	0	0	0	0	0
	11	+,0	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	12	NA	0	0	NA	NA	NA	NA	NA	NA	NA
II		+,0,*	+,0,*	0	+,0,*	0	0	0	0	0	0
III	1	+,0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	+,0,*	0,*	NA	0,*	NA	NA	NA	NA	NA
	3	+	+,0,*	NA	+	NA	NA	NA	NA	NA	NA
	4	+	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
IV	1	NA	NA	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	2	NA	*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	3	NA	*	0,*	+,0	0,*	+,0	NA	NA	NA	NA
	4	+	+,0,*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	5	+	+,0,*	NA	+,0	NA	NA	NA	NA	NA	NA
	6	+	+,0,*	0	+	NA	NA	NA	NA	NA	NA

+, manual   0, mechanized   *, automated

MF ACTION PARAMETER: LOCATE MATERIAL

EQPT KEY		SHEET METAL SIZE CATEGORIES									
		0	A	B	C	D	E	F	G	H	I
I	1	+,*	+,0,*	+,0,*	+,*	+,0,*	+,*	+,*	+,*	+,*	+,*
	2	NA	+,0,*	+,0,*	+,*	+,0,*	+,*	+,*	+,*	+,*	+,*
	3	NA	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
	4	+,*	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
	5	+,*	NA	NA	+,*	NA	NA	NA	NA	NA	NA
	6	NA	+,0,*	NA	+,*	NA	+,*	NA	NA	NA	NA
	7	NA	+,0,*	NA	+,*	NA	+,*	NA	NA	NA	NA
	8	NA	+,*	+,*	+,*	+,*	+,*	+,*	+,*	NA	NA
	9	NA	0,*	NA	0,*	NA	0	0	0	0	0
	10	NA	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*
	11	+	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
	12	NA	0,*	0,*	NA	NA	NA	NA	NA	NA	NA
II		0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*
III	1	+	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	+,0,*	+,0,*	NA	+,0,*	NA	NA	NA	NA	NA
	3	+,0,*	+,0,*	NA	+,0,*	NA	NA	NA	NA	NA	NA
	4	+	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
IV	1	NA	NA	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*
	2	NA	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*
	3	NA	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	NA	NA	NA	NA
	4	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*	+,0,*
	5	0,*	0,*	NA	0,*	NA	NA	NA	NA	NA	NA
	6	+,0,*	+,0,*	+,0,*	+,0,*	NA	NA	NA	NA	NA	NA

+, manual   0, mechanized   *, automated

MF ACTION PARAMETER: MOVE MATERIAL

EQPT KEY		SHEET METAL SIZE CATEGORIES									
		0	A	B	C	D	E	F	G	H	I
I	1	0	0	0	0	0	0	0	0	0	0
	2	NA	+,0	0	+,0	0	+,0	+,0	+,0	+,0	+,0
	3	NA	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	4	0	0	NA	NA	NA	NA	NA	NA	NA	NA
	5	0	NA	NA	0	NA	NA	NA	NA	NA	NA
	6	NA	0	NA	0	NA	0	NA	NA	NA	NA
	7	NA	0,*	NA	0,*	NA	0,*	NA	NA	NA	NA
	8	NA	+	+	+	+	+	+	+	+	+
	9	NA	0	NA	0	NA	0	0	0	0	0
	10	NA	0	0	0	0	0	0	0	0	0
	11	0	0	NA	NA	NA	NA	NA	NA	NA	NA
	12	NA	0,*	0,*	NA	NA	NA	NA	NA	NA	NA
II		0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*
III	1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	0,*	0,*	NA	0,*	NA	NA	NA	NA	NA
	3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IV	1	NA	NA	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*
	2	NA	*	*	*	*	*	*	*	*	*
	3	NA	0,*	0,*	0,*	0,*	0,*	NA	NA	NA	NA
	4	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*	0,*
	5	*	*	NA	*	NA	NA	NA	NA	NA	NA
	6	0,*	0,*	0,*	0,*	NA	NA	NA	NA	NA	NA

+, manual 0, mechanized *, automated

MF ACTION PARAMETER: UNLOAD MATERIAL

EQPT KEY		SHEET METAL SIZE CATEGORIES									
		0	A	B	C	D	E	F	G	H	I
I	1	+,0	+,0	0	+,0	0	0	0	0	0	0
	2	NA	+,0	0	+,0	0	0	0	0	0	0
	3	NA	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	4	+,0	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	5	+,0	NA	NA	+,0	NA	NA	NA	NA	NA	NA
	6	NA	+,0,*	NA	+,0,*	NA	0	NA	NA	NA	NA
	7	NA	+,0,*	NA	+,0,*	NA	0,*	NA	NA	NA	NA
	8	NA	+,0	0	+,0	0	0	0	0	NA	NA
	9	NA	0	NA	0	NA	0	0	0	0	0
	10	NA	+	0	+,0	0	0	0	0	0	0
	11	+	+	NA	NA	NA	NA	NA	NA	NA	NA
	12	NA	0,*	0,*	NA	NA	NA	NA	NA	NA	NA
II		+,0,*	+,0,*	0	+,0,*	0	0	0	0	0	0
III	1	+,0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	+,0,*	0,*	NA	0,*	NA	NA	NA	NA	NA
	3	+	+,0,*	NA	+	NA	NA	NA	NA	NA	NA
	4	+	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
IV	1	NA	NA	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	2	NA	*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	3	NA	*	0,*	+,0	0,*	+,0	NA	NA	NA	NA
	4	+	+,0,*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	5	+	+,0,*	NA	+,0	NA	NA	NA	NA	NA	NA
	6	+	+,0,*	0	+	NA	NA	NA	NA	NA	NA

+, manual 0, mechanized *, automated

MF ACTION PARAMETER: LOAD MATERIAL

EQPT KEY		SHEET METAL SIZE CATEGORIES									
		0	A	B	C	D	E	F	G	H	I
I	1	+,0	+,0	0	+,0	0	0	0	0	0	0
	2	NA	+,0	0	+,0	0	0	0	0	0	0
	3	NA	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	4	+,0	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	5	+,0	NA	NA	+,0	NA	NA	NA	NA	NA	NA
	6	NA	+,0	NA	+,0	NA	0	NA	NA	NA	NA
	7	NA	+,0	NA	+,0	NA	0	NA	NA	NA	NA
	8	NA	+,0	0	+,0	0	0	0	0	NA	NA
	9	NA	0	NA	0	NA	0	0	0	0	0
	10	NA	+	0	+,0	0	0	0	0	0	0
	11	+,0	+,0	NA	NA	NA	NA	NA	NA	NA	NA
	12	NA	0	0	NA	NA	NA	NA	NA	NA	NA
II		+,0,*	+,0,*	0	+,0,*	0	0	0	0	0	0
III	1	+,0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	2	NA	+,0,*	0,*	NA	0,*	NA	NA	NA	NA	NA
	3	+	+,0,*	NA	+	NA	NA	NA	NA	NA	NA
	4	+	+,0,*	NA	NA	NA	NA	NA	NA	NA	NA
IV	1	NA	NA	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	2	NA	*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	3	NA	*	0,*	+,0	0,*	+,0	NA	NA	NA	NA
	4	+	+,0,*	0,*	+,0	0,*	+,0	0,*	0,*	0,*	0,*
	5	+	+,0,*	NA	+,0	NA	NA	NA	NA	NA	NA
	6	+	+,0,*	0	+	NA	NA	NA	NA	NA	NA

+, manual   0, mechanized   *, automated

E-24-636

A PRELIMINARY INVESTIGATION OF

GROUP TECHNOLOGY CELLS USING SIMULATION

Submitted to

Research Triangle Institute

Submitted by

John A. White, Ph.D.
School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, GA 30332

March 1980

INTRODUCTION

Because of the MFC requirements to model GT cells, a preliminary investigation of a GT cell was performed using simulation. The results of the investigation are presented in this report; the GASP simulation program is described and preliminary conclusions are drawn. The computer program is written in standard FORTRAN IV, utilizing the Gasp IV simulation package. The program simulates a fictitious cell designed under Group Technology concepts.

Converting a manufacturing plant layout using a functional machine layout to one using Group Technology (G.T.) concepts may provide many benefits. However, to gain all of the G.T. benefits, the conversion must include all phases of the manufacturing environment. One of these phases is in production planning and scheduling. We believe scheduling for a G.T. system is more critical than it is for a functional layout because of the flexibility lost in G.T. In a functional layout, a job may have several machines to pick from in performing a certain operation; while in a G.T. cell, it may only have one or two. Incorrect scheduling of jobs in a G.T. cell may cause uneven loading of jobs on machines, large volumes of work-in-process (WIP) jobs in the cell, uneven material flows, and ultimately parts will not be produced to meet their due dates. Very little literature is available describing scheduling and lot sizing procedures for systems using G.T. Material flow and WIP storage allocation are major MFC concerns. It is the intent of this simulation to test different scheduling and lot sizing techniques in a G.T. cell to see how they affect material flows and WIP storage. While this simulation does not provide readily conclusive, clear-cut answers, it does show some advantages and disadvantages to a few commonly used scheduling techniques. A similar simulation could provide two benefits. Used as a layout design aid, individual cell layouts could be tested to measure the ability of the layout to meet desired operating specifications such as minimum queue size or maximum machine utilization. The second application might fall in the area of production planning and scheduling where a release schedule could be tested for its ability to meet operating specifications such as minimum time in the system, minimum WIP inventory, or minimum late orders filled.

The program is written in fairly general form to provide the user with the flexibility of being modified to suit desired needs. Some fairly gross assumptions were made in the program logic which may need to be altered to truly mimic a specific system.

Scheduling procedures used in a functional layout may be successful in meeting customer orders; yet, when applied to a G.T. shop, they might produce unacceptable WIP queues within production cells. Hence, it may become necessary to modify scheduling procedures to compromise slightly with meeting due dates in order that materials flow through a cell more smoothly.

Given Information:

The program is designed to simulate an 8 machine (5 machine groups), 16 part number Group Technology cell. Information was as follows.

MACHINE DATA

MACHINE	MACHINE GROUP CODE USED IN PROGRAM	NO. OF MACHINES	TIME BETWEEN FAILURES (HRS)	REPAIR TIME (HRS)
#454	1	1	141	2.7
#457	2	3	74	3.4
#461	3	1	112	2.6
#451	4	2	245	3.5
#463	5	1	56.5	4.1

Failure and repair times were estimated and were assumed constant.

PART DATA

			**** OPERATIONS IN SEQUENCE ****		
PART NO.	MONTHLY DEMAND	FT^3 PER PIECE	MACHINE NO.	SET-UP (HRS)	PROCESS TIME PER PIECE (HRS)
1	190	.03*	454	.3	.036
			457	3.0	.402
			457	3.0	.919
			457	4.0	.402
				10.3	1.759
2	310	.03*	454	3.0	.035
			457	3.0	.500
			457	3.0	.588
			457	.8	.507
				9.8	1.630
3	180	.0234	457	4.0	.405
			457	4.0	.151
				8.0	.556
4	190	.0186	457	3.0	.173
5	30	.03*	461	3.0	.670
			461	3.0	.123
			454	3.0	.155
				9.0	.948

PART DATA (cont'd)

PART NO.	MONTHLY DEMAND	FT^3 PER PIECE	**** OPERATIONS IN SEQUENCE **** MACHINE NO.	SET-UP (HRS)	PROCESS TIME PER PIECE (HRS)
6	110	.03*	461	3.0	.477
7	110	.03*	451	4.0	.917
			463	3.0	.665
			451	5.0	1.467
			454	5.0	.166
				17.0	2.487
8	110	.0239	463	3.0	.366
9	110	.0013	461	2.0	.196
			451	2.5	.423
				4.5	.619
10	110	.0017	461	3.0	.788
			451	3.0	.15
				6.0	.938
11	110	.03*	451	1.0	.622
			454	5.0	2.686
			463	5.5	.781
			451	3.0	1.586
			451	5.0	.784
			461	4.0	.12
				23.5	6.579

PART DATA (cont'd)

**** OPERATIONS IN SEQUENCE ****

PART NO.	MONTHLY DEMAND	FT^3 PER PIECE	MACHINE NO.	SET-UP (HRS)	PROCESS TIME PER PIECE (HRS)
12	110	.0048	461	3.0	.072
			461	6.0	.329
			461	2.0	.055
			451	6.0	.550
				17.0	1.006
13	110	.03*	463	6.0	.75
			463	4.0	.50
				10.0	1.25
14	110	.1554	461	5.0	.672
			461	4.0	.098
			457	4.0	.993
				13.0	1.763
15	110	.0795	461	3.0	.130
			451	5.0	.333
				8.0	.463
16	110	.0002	463	3.0	.22

*Denotes estimated value - no data available

LOTS PER MONTH

To determine how many lots per month to be run for each part, parts were ordered by decreasing value of their ratio of total process time to total set-up time for a month.

i.e.

Ratio = (Parts/Month x Hrs/Piece) + (Total Set-Up Hrs.)

The following ordered list resulted.

Part No.	Ratio
2	51.6
1	32.4
11	30.8
6	17.5
10	17.2
7	16.1
9	15.2
14	14.9
13	13.8
8	13.4
3	12.5
4	10.9
16	8.1
12	6.5
15	6.4
5	3.2

The rationale for this ordering is in studying the impact of set-up on the total run time for a particular part in a cell. In releasing more than one lot per month of a particular part number, the only increase in time will be that of an additional set-up. Thus a part number with a large ratio may be a good candidate for running more than one lot per month because the set-up does not contribute very much to total run-time. It is desired to have multiple runs per month to make machine load balancing easier due to the reduced time a lot will tie up a machine in any one operation. However as the above mentioned ratio gets smaller, the benefits of multiple lots per month will be overridden by increased set-up times contributing greatly to total run-time. The ratios themselves do not have any significance other than setting up a relative list (as on the previous page) where a part will never have a greater number of lots released per month than a part with a larger ratio. Different, more complicated ordering rules might be used.

SIMULATION RUNS

Using the previous ordering of part numbers, categories were assigned to the part numbers. An assigned category represents the number of lot releases per month, i.e. if part number 1 is assigned a category of 4 then it will be released 4 times per month or every $22 \div 4 = 5.5$ days. The lot size is determined by dividing the monthly demand of each part by the corresponding category. Categories were assigned somewhat arbitrarily, following the rule established with the ratio test that no part numbers will be assigned a category higher than a part number with a higher ratio. The following list represents the possible categories (lots/month) and the interarrival time of the lots.

Category	Interarrival Time of Lots (Days)
1	22
2	11
3	7.3
4	5.5

With a part number assigned a category, a corresponding delay allowance was assigned to the part. The delay allowance was used in determining a due date for a lot released into the system.

Due Date = time of entry into the system + total machine set-up + total run time + delay allowance

$$\text{Delay Allowance} = \min \begin{cases} \text{- 5 days} \\ \text{- length of time for next arrival} \\ \quad \text{minus the total process time} \end{cases}$$

i.e.

category = 3

process time = 73 hrs. ÷ 21.5 hrs/day = 3.4 days

next lot due in 7.3 days

$$\text{Delay Allowance} = \min \begin{bmatrix} 5 \text{ days} \\ 7.3 - 3.4 \end{bmatrix} = 3.9 \text{ days} = 83.9 \text{ hrs.}$$

Three sets of category lists were assigned for the purpose of comparison in the simulation runs. The following page represents the three category lists with corresponding lot sizes and delay allowances. Note that part numbers are ordered by the ratio rule. Parts 2 and 11 are assigned delay allowances of zero as the total process times for each are greater than the machine hours available. Each part will always be considered late.

Part No.	Monthly Demand (units)	RUNS 1 - 3 Category (runs/mo)	Lot Process Time (hrs)	Delay Allowance (hrs)	Lot Size (units)	RUNS 4 - 6 Category (runs/mo)	Lot Process Time (hrs)	Delay Allowance (hrs)	Lot Size (units)	RUNS 7 - 9 Category (runs/mo)	Lot Process Time (hrs)	Delay Allowance (hrs)	Lot Size (units)
2	310	3	178.2	0	103	4	136.1	0	78	4	136.1	0	78
1	190	2	177.4	59.1	95	4	93.9	24.4	48	3	121.7	32.3	63
11	110	2	385.4	0	55	4	204.4	0	28	3	264.7	0	37
6	110	1	55.5	108	110	3	20.5	108	37	2	29.3	108	55
10	110	1	109.2	108	110	3	30.3	108	37	2	57.6	108	55
7	110	1	290.6	108	110	3	108.2	48.8	37	2	153.8	82.7	55
9	110	1	101.1	108	110	3	37.4	108	37	2	53.3	108	55
14	110	1	206.9	108	110	3	77.6	79.4	37	2	110.0	108	55
13	110	1	147.5	108	110	2	78.8	108	55	1	147.5	108	110
8	110	1	43.3	108	110	2	23.2	108	55	1	43.3	108	110
3	180	1	108.1	108	180	2	58.1	108	90	1	108.1	108	180
4	190	1	35.9	108	190	2	19.5	108	95	1	35.9	108	190
16	110	1	27.2	108	110	1	27.2	108	110	1	27.2	108	110
12	110	1	127.7	108	110	1	127.7	108	110	1	127.7	108	110
15	110	1	58.9	108	110	1	58.9	108	110	1	58.9	108	110
5	30	1	37.4	108	30	1	37.4	108	30	1	37.4	108	30

SCHEDULING & PRIORITIES

To begin the simulation, the first lot of each part was scheduled according to the part's category. Assuming a uniform flow of lots arriving into the system, first lots for parts having category 1 were each scheduled to arrive sometime between the start of the simulation and the end of the first month (22 days). This was performed by pulling arrival dates from a uniform distribution, a function internal to the GASP IV program. Likewise first lots of category 2 parts were scheduled between zero and 11 days, category 3 parts between zero and 7.3 days, and category 4 parts between zero and 5.5 days. Subsequent arrivals of similar lots then arrived throughout the simulation every X days where X = 22, 11, 7.3, 5.5 days for categories 1, 2, 3, 4 respectively.

First operations of each arriving lot were scheduled immediately if a machine needed for the first operation was available. Otherwise the lot was put on a dispatch list to designate that the lot is in a specific machine queue. The same process is used for subsequent operations. When the machine is free, ready for the next job, the dispatch list for that machine is scanned and a job is pulled off the list according to a specific priority rule designated by the program data file.

Three different priority roles were tested for each of the three category lists. The first was earliest due date first. Systems using this priority generally do quite well in meeting customer orders on a timely basis. However, queue control is weak.

The second priority rule is that of scheduling the next job from the dispatch list having the smallest total processing time for the operation to be performed. This rule, frequently used in job-shop situations, generally levels the queue sizes fairly well, however one might expect an increase in late orders.

The third priority rule tested is contrary to that of the previous rule in that jobs are prioritized according to greatest total processing time of the operation to be performed. This is a weak scheduling rule and should demonstrate the problems which might occur when a foreman or machine operator repeatedly makes poor selections for the next job to be processed.

MACHINE FAILURES

The following estimates of machine failures and repairs were used in the simulation.

Machine Group	Failure Interarrival Time (hrs.)	Repair Time (hrs.)
454	141	2.7
461	112	2.6
451	245	3.5
457	74	3.4
463	56.5	4.1

In the program each time a job was to start on a machine, a check was made to see if a failure would occur before the operation was finished. If so the repair time was added to the processing time, calculating the total time the machine would be in use, the next failure was scheduled, and the number of failures was incremented. If not, the time until next failure was decremented by the operation run time and the operation was performed as scheduled.

SAMPLE

SIMULATION OUTPUT

There are 12 basic pieces of information on which statistics are collected during the simulation. Description of these statistics with reference to the sample output accompanying this section is as follows.

Table 1 - This table summarizes the simulated characteristics of each of the part numbers. Average lateness and average earliness include only the values which were late or early, respectively.

Table 2a - Represents the average number of lots of each part number which is present in the system throughout the simulation. The values are calculated automatically through the program using GASP time integrated statistical variables.

Table 2b - Corresponds to Table 2a statistics. Each value is equal to the value in Table 2a times the lot size for that part number. Very important system measure.

Table 2c - Corresponds to Table 2b statistics. Values are equal to Table 2b times cubic foot volume for that part.

Table 3a - Represents the number of failures which occurred on each of the eight machines during the simulation run of one year.

Table 3b - Represents the number of times any machine broke down while any one part number was being worked on.

Table 3c - ISAME is the number of times that a part might have had two consecutive operations performed on the same machine. ISAME 1 is the number of times that the part was actually pulled back out of the dispatch list for that second operation on the same machine due to its highest priority. PER = (ISAME 1 ÷ ISAME) x 100. In practice if an operator always kept a part on a machine for consecutive operations, he would have made the wrong decision according to scheduling priorities 100-PER percent of the time.

Table 3d - Measure of the number of times jobs had to wait to enter a machine group for an operation as well as the average duration in hours spent in the queue.

Table 4a - Statistics on total average waiting time in system for each part. Includes queue times and machine repair times.

Table 4b - UTIL (I), I = 1 to 8 is a measure of the machine utilization for machine I during the simulation.

VOLIN 1 through VOLIN 5 represents statistics collected for the cubic volume of parts queued in front of the 5 machine groups, averaged over simulation time.

LOTS 1 through LOTS 5 collect statistics on the number of lots queued in front of the 5 machine groups, averaged over simulation time.

LOTS 1-5 and VOLIN 1-5 do not include the jobs being processed on each of the machine groups.

JOB PART NUMBER

7	8	9	10	11	12	13	14	15	16
23	24	23	24	46	23	24	23	24	23
0	23	0	24	0	0	16	0	7	23
23	1	23	0	46	23	8	23	17	0
0	0	0	0	0	0	0	0	0	0
.95	20.75	58.72	I	410.09	73.18	15.06	116.79	60.36	I
I	48.86	I	50.48	I	I	16.29	I	20.34	99.16
.66	20.75	78.84	0.00	496.77	107.81	86.55	134.57	83.81	0.00
.00	108.00	0.00	73.72	0.00	0.00	40.80	0.00	20.71	108.00
.17	62.04	117.69	38.02	59.95	64.44	43.16	96.78	103.52	8.84

TABLE 2

AVERAGE VOLUME IN THE SYSTEM
MEAN = 33.934 STD. DEV = 10.475

a)

AVERAGE NUMBER OF LOT TYPES IN THE SYSTEM

LOT NO	MEAN	STD. DEV
1	1.39	.51
2	1.64	.53
3	.49	.50
4	.08	.27
5	.31	.46
6	.12	.33
7	.90	.30
8	.22	.42
9	.39	.49
10	.31	.46
11	1.83	.47
12	.40	.49
13	.40	.49
14	.62	.49
15	.34	.47
16	.07	.26

b)

AVERAGE NUMBER OF UNITS OF EACH TYPE IN THE SYSTEM

PART NO	MEAN	STD. DEV
1	132.16	48.39
2	169.34	54.91
3	88.93	89.99
4	14.56	50.54
5	9.32	13.88
6	13.54	36.14
7	99.09	33.13
8	24.49	45.76
9	42.65	53.59
10	34.23	50.93
11	100.87	26.01
12	43.46	53.78
13	44.34	53.96
14	68.31	53.36
15	37.70	52.21
16	8.23	28.95

c)

AVERAGE TOTAL CU. FT. OF LOT TYPES IN THE SYSTEM

PART NO.	MEAN	STD. DEV
1	3.96	1.45
2	5.08	1.65
3	2.08	2.11
4	.27	.94
5	.28	.42
6	.41	1.08
7	2.97	.99
8	.59	1.09
9	.06	.07
10	.06	.09
11	3.03	.78
12	.21	.26
13	1.33	1.62
14	10.62	8.29
15	3.00	4.15
16	.00	.01

TABLE 3

a)

NUMBER OF FAILURES PER MACHINE

MACHINE 1	NUMBER OF FAILURES = 61
MACHINE 2	NUMBER OF FAILURES = 143
MACHINE 3	NUMBER OF FAILURES = 109
MACHINE 4	NUMBER OF FAILURES = 107
MACHINE 5	NUMBER OF FAILURES = 65
MACHINE 6	NUMBER OF FAILURES = 30
MACHINE 7	NUMBER OF FAILURES = 27
MACHINE 8	NUMBER OF FAILURES = 156

b)

NO. OF FAILURES WHILE PART ON MACHINES

PART 1	NUMBER OF FAILURES = 110
PART 2	NUMBER OF FAILURES = 185
PART 3	NUMBER OF FAILURES = 37
PART 4	NUMBER OF FAILURES = 0
PART 5	NUMBER OF FAILURES = 11
PART 6	NUMBER OF FAILURES = 3
PART 7	NUMBER OF FAILURES = 44
PART 8	NUMBER OF FAILURES = 23
PART 9	NUMBER OF FAILURES = 15
PART 10	NUMBER OF FAILURES = 17
PART 11	NUMBER OF FAILURES = 110
PART 12	NUMBER OF FAILURES = 18
PART 13	NUMBER OF FAILURES = 63
PART 14	NUMBER OF FAILURES = 47
PART 15	NUMBER OF FAILURES = 8
PART 16	NUMBER OF FAILURES = 7

c)

ISAME = 424
ISAME1= 378
PER = 89.2

d)

GROUP 1	129 ENTERED QUEUE	AVG. QTIME = 94.16
GROUP 2	117 ENTERED QUEUE	AVG. QTIME = 44.26
GROUP 3	181 ENTERED QUEUE	AVG. QTIME = 39.84
GROUP 4	119 ENTERED QUEUE	AVG. QTIME = 52.51
GROUP 5	133 ENTERED QUEUE	AVG. QTIME = 32.59

TABLE 4

STATISTICS FOR VARIABLES BASED ON OBSERVATION

	MEAN	STD DEV	SD OF MEAN	CV	MINIMUM	MAXIMUM	OBS
AVGWT1	.3714E+02	.6594E+02	.4771E+01	.1775E+01	0.	.1897E+03	191
AVGWT2	.1974E+02	.3825E+02	.2266E+01	.1938E+01	0.	.1581E+03	285
AVGWT3	.6483E+02	.5767E+02	.8503E+01	.8895E+00	0.	.1726E+03	46
AVGWT4	.3806E+00	.1555E+01	.3175E+00	.4087E+01	0.	.7517E+01	24
AVGWT5	.3596E+02	.4631E+02	.5458E+01	.1288E+01	0.	.1201E+03	72
AVGWT6	.2329E+01	.6364E+01	.1299E+01	.2732E+01	0.	.3064E+02	24
AVGWT7	.1618E+02	.2811E+02	.2915E+01	.1737E+01	0.	.8262E+02	93
AVGWT8	.5811E+02	.3263E+02	.6661E+01	.5615E+00	0.	.1083E+03	24
AVGWT9	.5709E+02	.3890E+02	.5674E+01	.6813E+00	0.	.1122E+03	47
AVGWT10	.1784E+02	.1031E+02	.1486E+01	.5779E+00	.1856E+02	.4077E+02	48
AVGWT11	.3556E+01	.1531E+02	.9118E+00	.1790E+01	0.	.1260E+03	282
AVGWT12	.1506E+02	.2775E+02	.2847E+01	.1843E+01	0.	.8967E+02	95
AVGWT13	.1620E+02	.1853E+02	.2679E+01	.1144E+01	0.	.7479E+02	48
AVGWT14	.3026E+02	.4105E+02	.4342E+01	.1357E+01	0.	.9926E+02	[illegible]
AVGWT15	.5128E+02	.2983E+02	.4305E+01	.5817E+00	0.	.1268E+03	48
AVGWT16	.7273E+01	.1109E+02	.2263E+01	.1524E+01	0.	.4718E+02	24

a)

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN	STD DEV	MINIMUM	MAXIMUM	TIME INTERVAL	CUR. VALUE
UTIL(1)	.7727E+00	.4191E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(2)	.8272E+00	.3781E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(3)	.7789E+00	.4150E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(4)	.7903E+00	.4071E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(5)	.8360E+00	.3703E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(6)	.8170E+00	.3867E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(7)	.8224E+00	.3822E+00	0.	.1000E+01	.1135E+05	.1000E+01
UTIL(8)	.8715E+00	.3347E+00	0.	.1000E+01	.1135E+05	.1000E+01
QCUFT1	.1070E+01	.9989E+00	0.	.3000E+01	.1135E+05	0.
QCUFT2	.4597E+00	.5416E+00	0.	.3000E+01	.1135E+05	.1000E+01
QCUFT3	.6408E+00	.6448E+00	0.	.4000E+01	.1135E+05	.1000E+01
QCUFT4	.5507E+00	.6568E+00	0.	.3000E+01	.1135E+05	.1000E+01
QCUFT5	.2957E+00	.4833E+00	0.	.2000E+01	.1135E+05	0.
QLOTS1	.3165E+01	.3033E+01	-.1421E-11	.9240E+01	.1135E+05	-.1421E-11
QLOTS2	.1779E+01	.2351E+01	-.3610E-11	.2440E+02	.1135E+05	.4212E+01
QLOTS3	.-317E+01	.6684E+01	-.1165E-10	.1964E+02	.1135E+05	.1709E+02
QLOTS4	.1287E+01	.2818E+01	-.1648E-11	.1205E+02	.1135E+05	.5280E+00
QLOTS5	.6990E+00	.1217E+01	-.4263E-12	.5929E+01	.1135E+05	-.4263E-12
#INSYS	.2553E+02	.2257E+01	0.	.3000E+02	.1135E+05	.2700E+02

b)

- SIMULATION OUTPUTS -

DESCRIPTION OF SIMULATION RUNS

CATEGORY LIST	RUN NUMBER		DISPATCH LIST PRIORITY RULE
1	1	(A)	EARLIEST DUE DATE FIRST
1	2	(B)	SMALLEST SUBSEQUENT OPERATION TIME BASED ON TOTAL TIME ON MACHINE
1	3	(C)	GREATEST SUBSEQUENT OPERATION TIME BASED ON TOTAL TIME ON MACHINE
2	4		(A)
2	5		(B)
2	6		(C)
3	7		(A)
3	8		(B)
3	9		(C)

PART NUMBER	RUNS 1	2	3	4	5	6	7	8	9
1	1.39	1.39	1.74	1.38	1.20	3.74	1.27	1.12	4.40
2	1.64	1.51	2.05	1.36	1.33	2.12	1.66	1.55	9.75
3	.49	.37	.27	.45	.30	1.64	.35	.24	.27
4	.08	.08	.24	.18	.09	1.32	.09	.08	.19
5	.31	.29	.41	.18	.19	.83	.29	.21	.63
6	.12	.13	.12	.29	.24	.20	.17	.16	.14
7	.90	.92	.86	1.31	1.50	1.61	1.51	1.25	1.70
8	.22	.15	.25	.16	.13	.45	.12	.12	.12
9	.39	.28	.35	.68	.41	1.16	.46	.37	.75
10	.31	.29	.35	.61	.59	1.05	.41	.34	.56
11	1.83	1.93	2.53	2.19	2.29	3.73	2.25	2.30	3.79
12	.40	.49	.59	.32	.33	.56	.35	.31	.55
13	.40	.39	.39	.52	.62	.40	.48	.51	.33
14	.62	.81	.64	.74	.75	1.05	.69	.62	.66
15	.34	.26	.40	.19	.19	.17	.19	.15	.21
16	.07	.07	.07	.19	.09	.27	.14	.11	.12
TOTAL	9.51	9.36	11.26	10.75	10.25	20.30	10.43	9.44	18.17
		*			*			*	

PART NUMBER	RUNS 1	2	3	4	5	6	7	8	9
1	132.2	131.7	165.6	66.4	57.8	179.5	79.9	70.8	277.2
2	169.3	156.0	210.8	105.7	103.7	165.0	129.4	121.2	292.7
3	88.9	66.0	49.2	40.7	26.6	147.5	63.3	44.1	48.2
4	14.6	15.0	45.6	16.8	8.7	125.6	17.3	14.6	35.3
5	9.3	8.8	12.4	5.5	5.6	24.9	8.6	6.2	19.0
6	13.5	14.5	13.2	10.9	8.9	7.3	9.5	9.0	7.6
7	99.1	101.7	94.9	48.6	55.6	59.7	83.0	68.9	93.7
8	24.5	16.7	27.5	9.1	7.4	25.0	12.9	13.4	12.8
9	42.7	31.3	38.8	25.0	15.1	42.8	25.5	20.3	41.1
10	34.2	31.9	38.5	22.5	21.7	38.9	22.4	18.5	30.8
11	100.9	106.0	139.1	61.2	64.2	104.4	83.4	85.1	140.4
12	43.5	55.5	64.8	34.9	36.7	62.1	38.5	34.0	60.9
13	44.3	43.1	43.4	28.7	34.0	22.2	52.7	55.7	36.4
14	68.3	89.2	70.4	27.5	27.7	38.9	38.0	33.8	36.5
15	37.7	28.9	43.5	21.3	20.4	18.7	21.2	16.9	23.2
16	8.2	7.6	7.6	20.9	9.8	29.4	15.6	12.5	13.5
TOTAL	931.2	903.9	1065.3	545.7	503.9	1091.9	701.2	625.0	1169.3
					*				

PART NUMBER	RUNS 1	2	3	4	5	6	7	8	9
1	3.96	3.95	4.97	1.99	1.73	5.39	2.40	2.12	8.32
2	5.08	4.68	6.32	3.17	3.11	4.95	3.88	3.64	8.78
3	2.08	1.55	1.15	.95	.62	3.45	1.48	1.03	1.13
4	.27	.28	.85	.31	.16	2.34	.32	.27	.66
5	.28	.26	.37	.17	.17	.75	.26	.19	.57
6	.41	.44	.40	.33	.27	.22	.28	.27	.23
7	2.97	3.05	2.85	1.46	1.67	1.79	2.49	2.07	2.81
8	.59	.40	.66	.22	.18	.60	.31	.32	.31
9	.06	.04	.05	.03	.02	.06	.03	.03	.05
10	.06	.05	.07	.04	.04	.07	.04	.03	.05
11	3.03	3.18	4.17	1.84	1.92	3.13	2.50	2.55	4.21
12	.21	.26	.31	.17	.18	.30	.18	.16	.29
13	1.33	1.29	1.30	.86	1.02	.66	1.58	1.67	1.09
14	10.62	13.87	10.99	4.27	4.31	6.04	5.91	5.26	5.66
15	3.00	2.29	3.41	1.69	1.62	1.49	1.68	1.34	1.84
16	.00	0	0	0.00	.00	.01	.00	.00	.00
TOTAL	33.95	35.59	37.92	17.50	17.02	31.25	22.78	20.95	36.00
					*				

	Queue	1	2	3	4	5	6	7	8	9
	1	1.07	1.17	1.56	.70	.53	2.47	1.09	.77	4.27
Average Cu. Ft.	2	.46	.40	.86	.57	.34	4.85	.43	.24	3.39
in Queues	3	.64	.59	1.20	1.20	1.02	2.70	.56	.46	1.22
	4	.55	.42	.61	.63	.61	1.99	.98	.62	2.02
	5	.30	.27	.56	.60	.68	1.27	.62	.59	.63
	1	3.17	3.14	4.26	1.04	.67	3.81	2.07	1.50	8.09
	2	1.78	2.96	2.67	1.31	.82	9.08	1.65	.80	7.38
Average No. of	3	4.32	5.57	5.28	1.91	1.91	4.24	1.79	1.28	2.11
Lot in Queues	4	1.29	.62	1.79	.46	.56	.76	1.17	.65	2.20
	5	.70	.57	1.17	.60	.82	1.17	1.05	1.09	.79
Average No. of Lots in System		25.53	25.37	27.27	26.76	26.24	36.31	26.43	25.45	34.18

OPERATING UNIT: PREPARED BY: DATE:

		1	2	3	4	5	6	7	8	9
TOTAL LOTS SERVED		469	469	467	921	924	919	659	660	647
NO. PAST DUE DATE		320	297	312	457	438	597	398	356	400
% LATE		68.2	63.3	66.8	49.6	47.4	65.1	60.4	53.9	61.8
% OF TIME COSECUTIVE OPERATIONS WERE DONE ON A MAHINE WITH NO JOBS BETWEEN		89.2	91.3	60.0	91.9	77.7	56.9	86.1	81.8	51.1
	QUEUE									
TOTAL NO. IN Q	1	117	93	168	227	194	280	208	186	241
AVERAGE Q TIME		94.26	91.93	125.7	37.97	30.78	97.39	59.13	47.13	200.6
TOTAL NO. IN Q	2	117	93	168	227	248	420	129	143	302
AVERAGE Q TIME		44.26	47.93	57.95	28.08	15.68	131.1	37.32	18.78	120.9
TOTAL NO. IN Q	3	181	192	243	432	434	529	309	260	352
AVERAGE Q TIME		39.84	34.65	55.75	31.45	26.67	57.58	20.38	20.00	38.42
TOTAL NO. IN Q	4	119	100	135	354	393	461	274	326	327
AVERAGE Q TIME		52.51	47.15	51.37	20.21	17.59	49.03	40.57	21.59	70.01
TOTAL NO. IN Q	5	103	104	98	265	276	256	165	155	126
AVERAGE Q TIME		32.59	29.34	64.44	25.86	27.76	56.13	42.51	42.99	57.00

OPERATING UNIT:

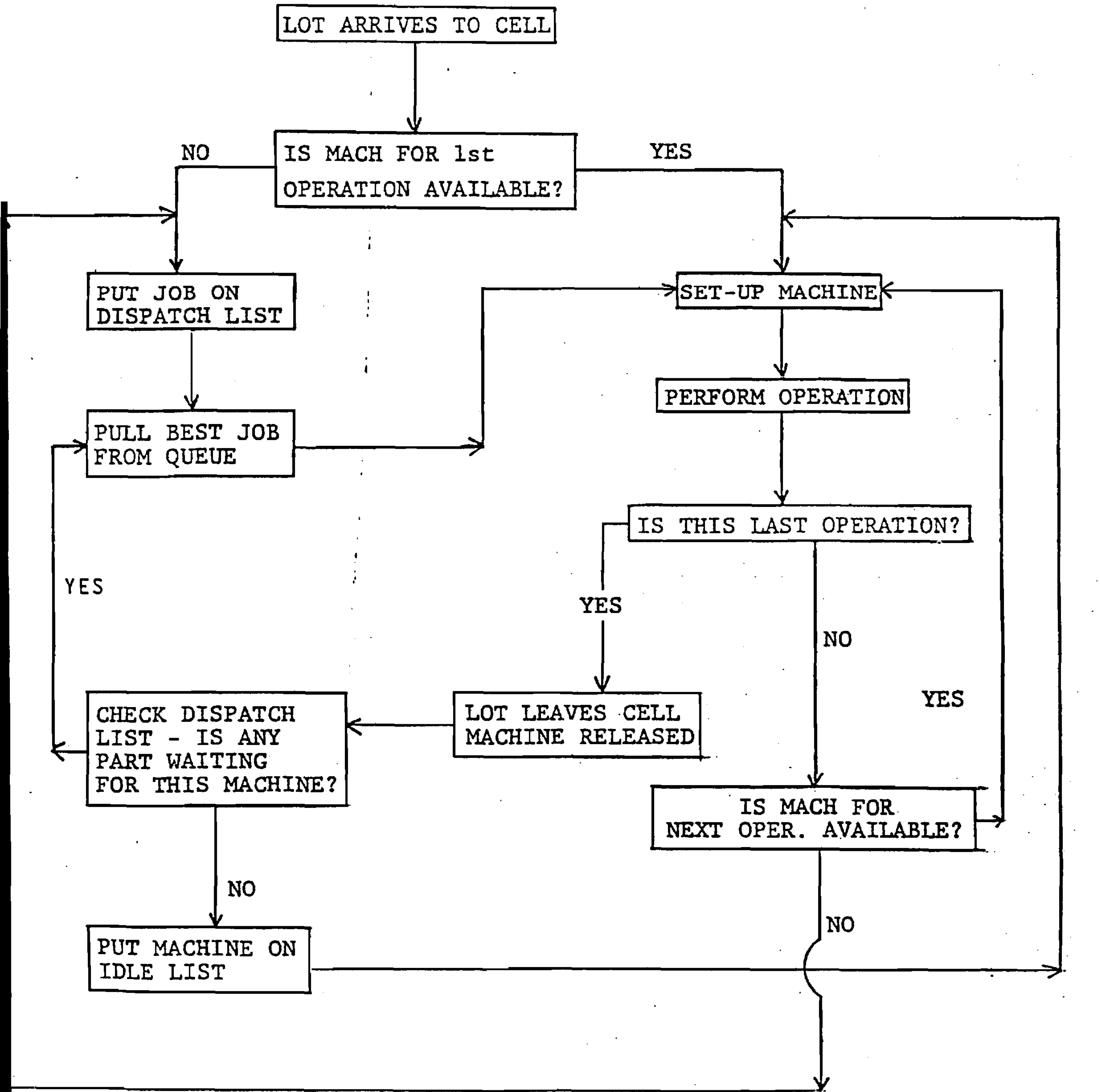
PREPARED BY:

DATE:

		RUNS								
		1	2	3	4	5	6	7	8	9
	PN									
	1	37.1	36.4	60.3	16.6	11.1	16.6	18.4	12.6	148.0
	2	19.7	14.8	35.6	5.3	4.4	5.3	14.3	11.0	77.3
	3	64.8	33.5	10.6	24.3	5.5	24.3	30.7	4.6	9.6
	4	38.1	1.4	78.9	22.3	1.9	22.3	6.9	.3	52.2
	5	36.0	33.3	52.0	16.1	16.8	16.1	32.3	19.6	86.9
	6	2.3	5.7	1.1	24.9	16.7	24.9	11.1	9.3	3.1
	7	16.2	18.9	11.3	17.6	25.0	17.6	42.2	25.8	53.4
AVG. DELAY	8	58.1	26.1	72.4	14.8	7.5	14.8	9.8	12.7	10.6
IN CELL	9	57.1	32.5	49.4	39.7	18.2	39.7	35.8	24.8	70.5
	10	17.8	12.8	26.4	27.0	25.4	27.0	18.8	10.3	36.6
	11	8.6	12.3	37.9	8.2	10.4	8.2	14.7	16.1	57.1
	12	15.1	25.9	39.0	6.1	8.3	6.1	9.4	4.8	34.4
	13	16.2	13.1	14.0	19.7	30.4	19.7	36.4	43.4	1.8
	14	30.3	61.2	33.0	12.3	12.5	12.3	17.6	11.5	15.4
	15	51.3	32.2	63.6	16.2	14.2	16.2	15.7	6.4	20.3
SPACE	16	7.3	4.8	5.6	61.6	13.0	61.6	40.9	26.6	30.4
	MACH									
	1	77.3	77.1	76.7	84.1	84.2	84.1	81.1	81.0	79.8
	2	82.7	77.3	81.4	84.2	86.2	84.2	83.0	78.3	79.3
MACHINE	3	77.9	79.1	81.8	85.3	82.7	85.3	79.9	83.0	79.6
UTILIZATION	4	79.0	83.6	74.9	83.8	85.1	83.8	83.3	86.2	80.3
(%)	5	83.6	83.6	84.1	94.1	94.3	94.1	89.1	88.5	88.6
	6	81.7	87.9	81.8	89.9	89.9	89.9	85.2	85.7	85.5
	7	82.2	76.4	81.1	89.0	89.5	89.0	86.0	86.0	85.0
	8	87.2	87.1	86.7	94.9	94.9	94.9	88.3	88.3	87.7
AVERAGE		81.5	81.5	81.1	88.2	88.4	88.2	84.5	84.6	83.2

- APPENDIX -

GENERAL PROGRAM FLOW



SUBROUTINE DESCRIPTION

MAIN SUBROUTINES- GASP DEFINED

GASP - The GASP main simulation processor.

INTLC - User-written, GASP supplied routine to initialize system variables.

EVNTS - User-written, GASP supplied routine to schedule events from events file #1.

ARRVL - User-written, user-supplied routine that simulates the arrival of a lot at a specific machine group. EVENT TYPE 1.

SERVCOM - User-written,user-supplied routine that simulates the completion of service on a lot by a specific machine group. EVENT TYPE 2.

OTPUT - User-written, GASP-supplied routine to output variable values in descriptive format

USER DEFINED SUPPORT ROUTINES

CALL STA - Routine to collect variable statistics

CALL BATCHGEN - Routine to create lots with specific characteriztics(attributes) for entry into the cell

CALL BRKDWN - Routine to simulate the failure of an in-process machine

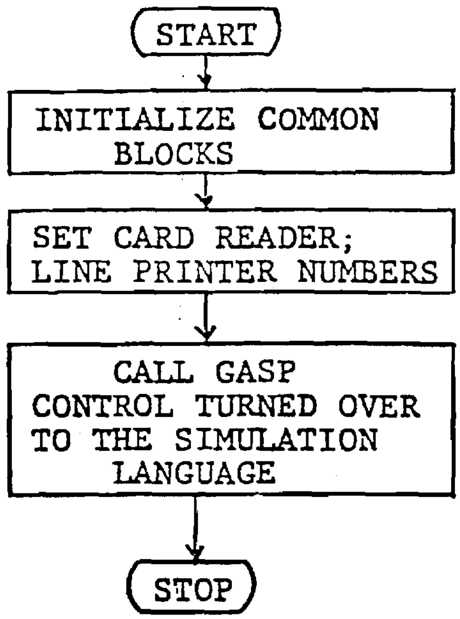
CALL DOWNT - Routine to generate a repair time

CALL FAILURE - Routine to generate the next failure

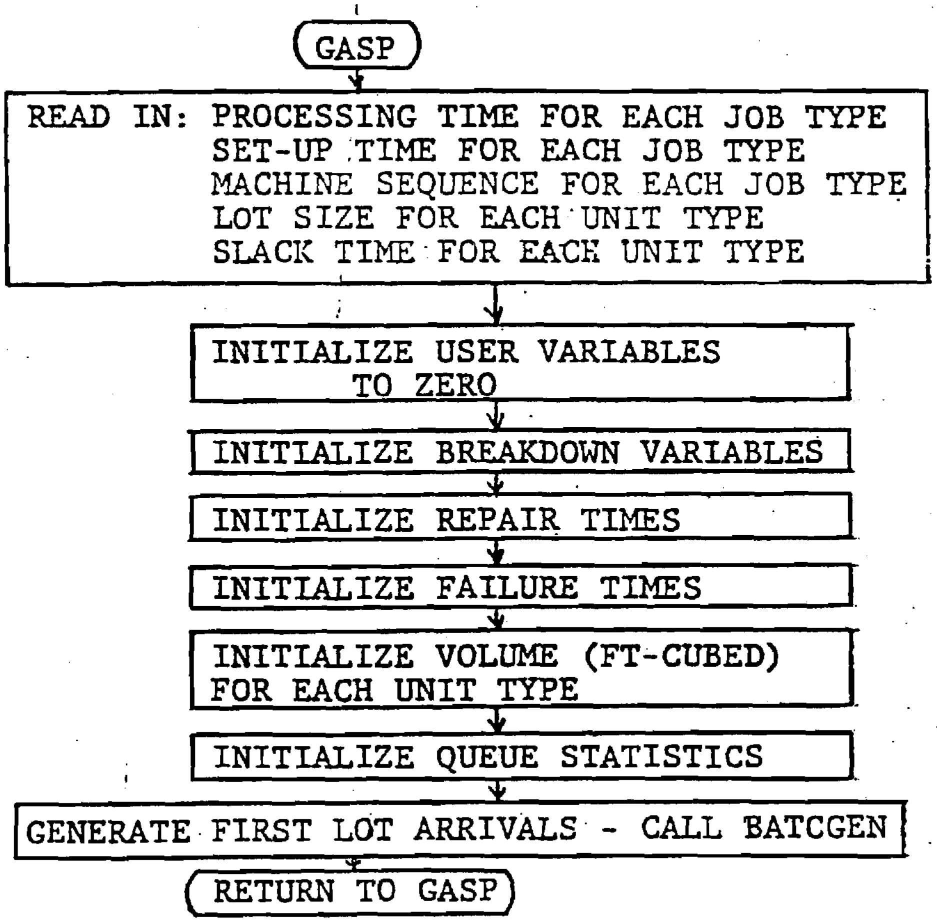
CALL SEARCH - Routine to determine the availability of a machine for processing a specific lot.

PROGRAM FLOW

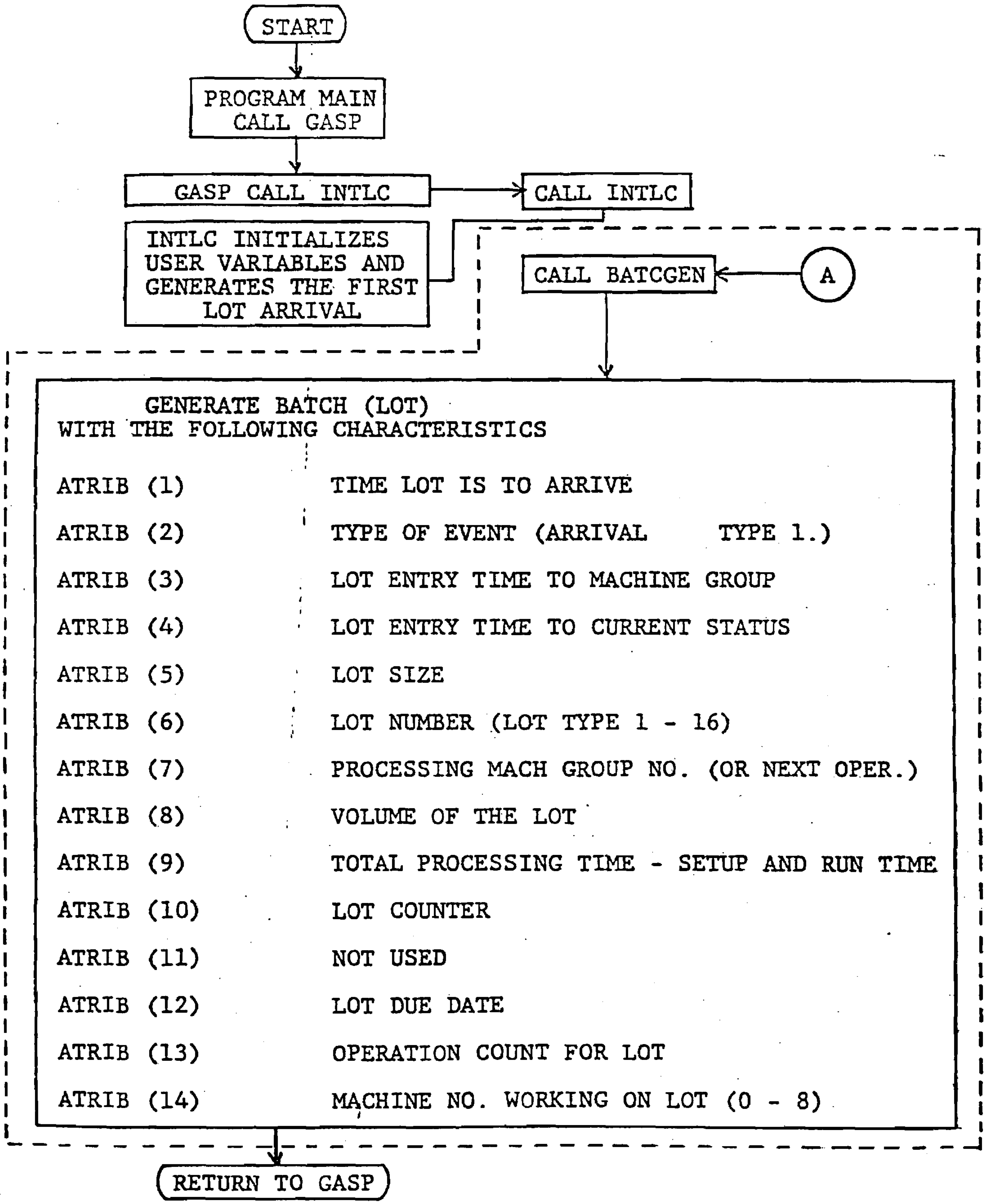
PROGRAM MAIN



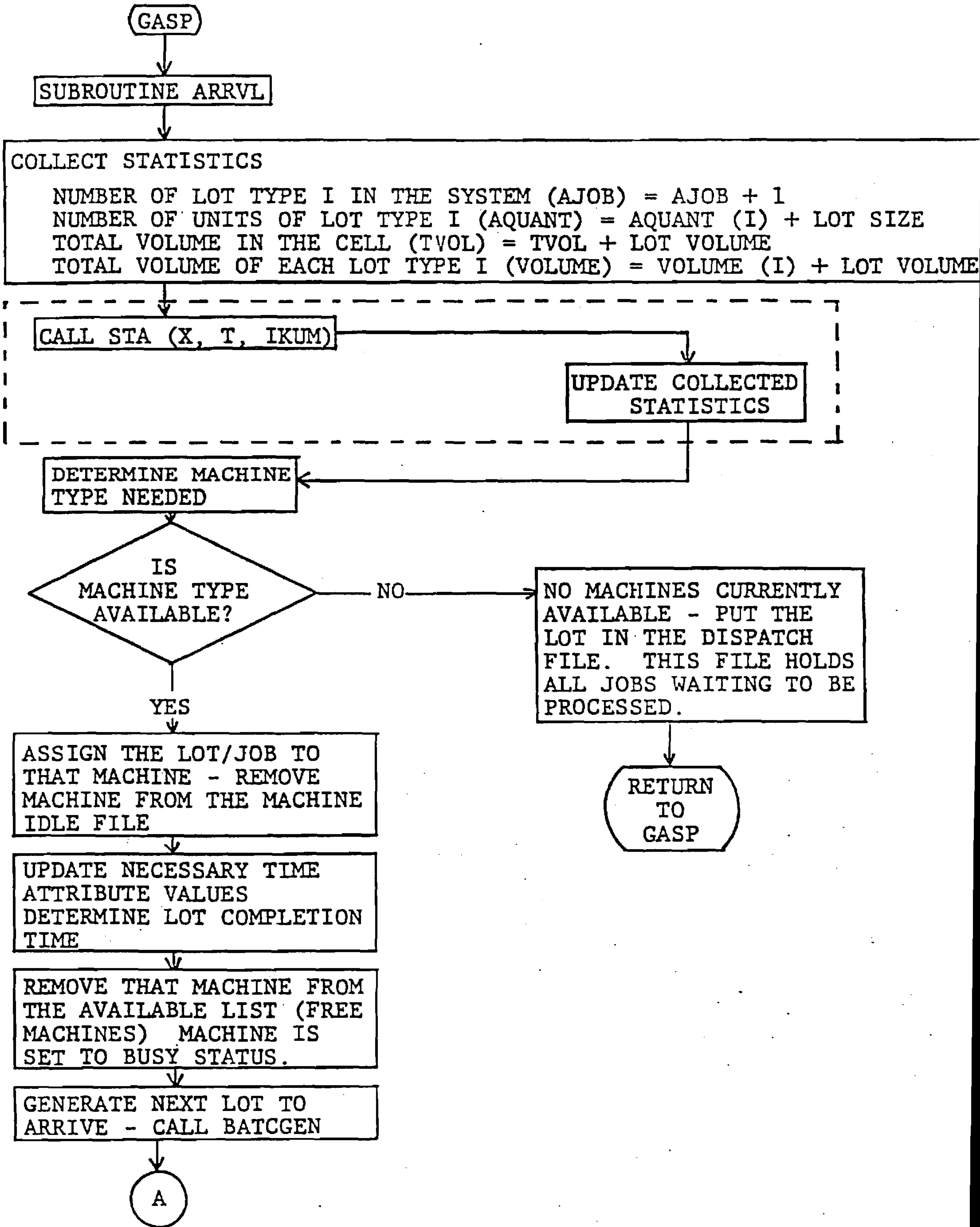
SUBROUTINE INTLC



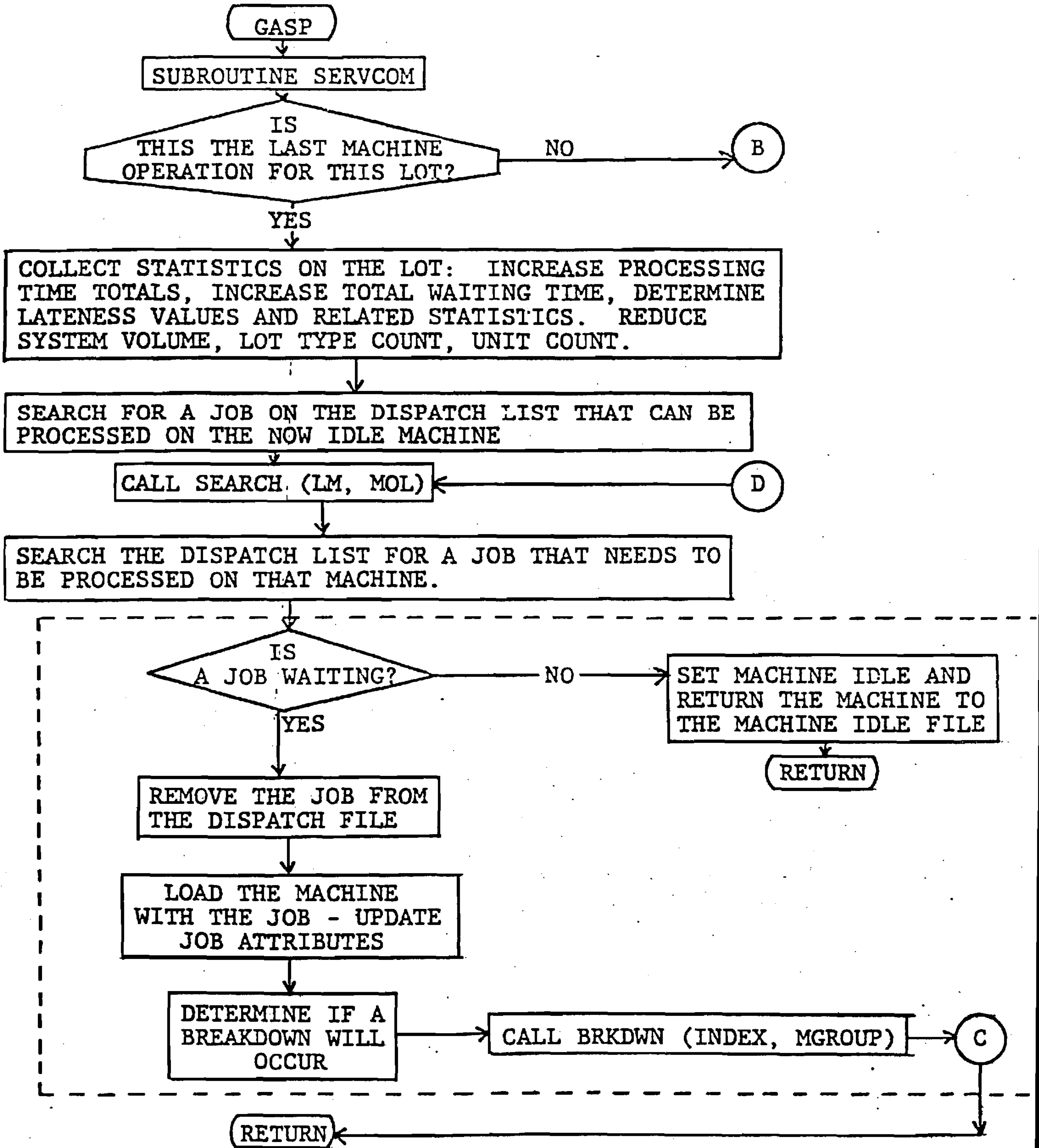
THE PROGRAM FLOW WILL BE EXPLAINED IN TERM OF A LOT FLOWING THROUGH THE SYSTEM



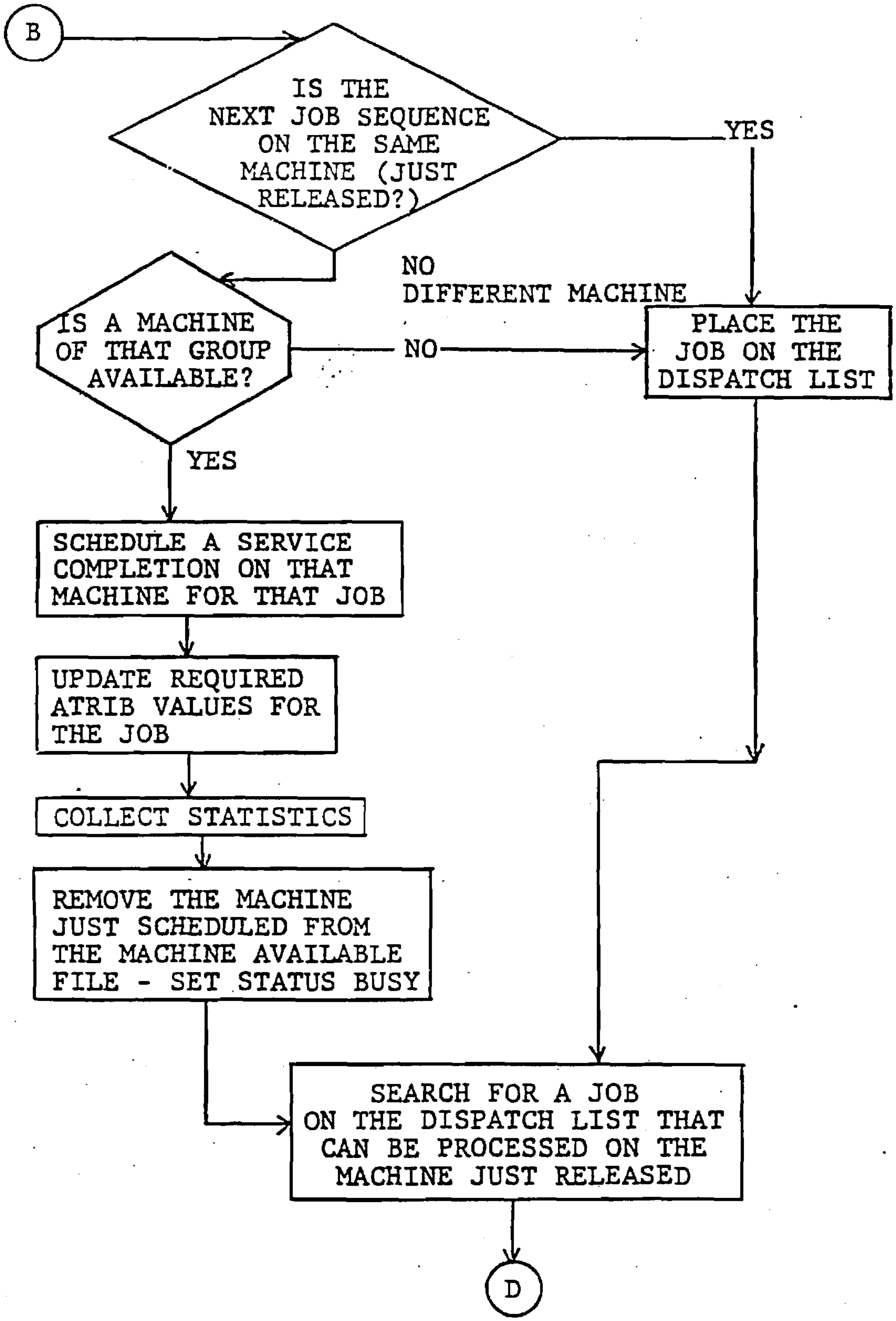
THIS IS A LOT ARRIVAL, GASP MAIN WILL SET IX = 1, SUBROUTINE EVNTS WILL CALL EVENT TYPE 1, SUBROUTINE ARRVL



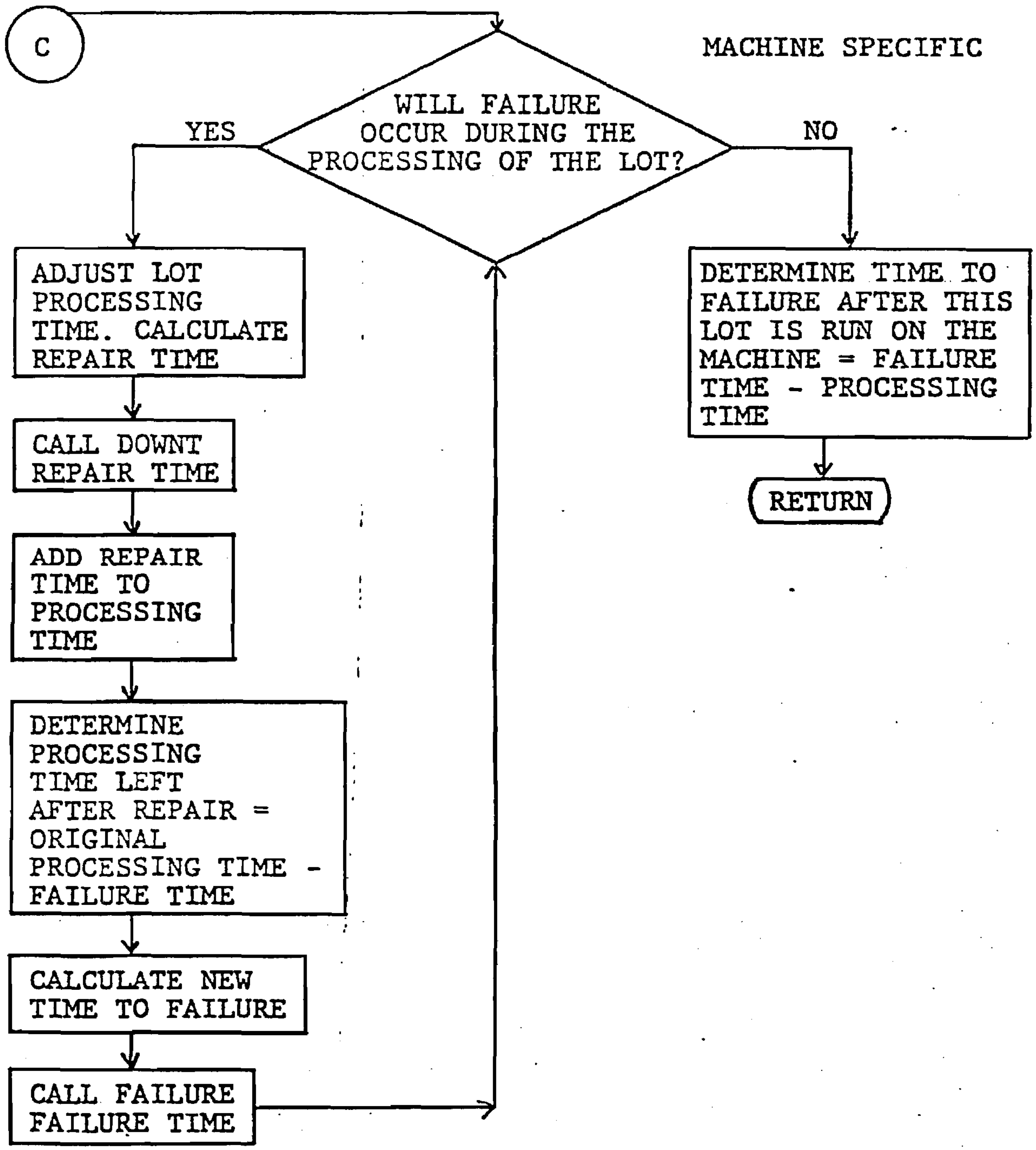
GASP WILL CHECK THE NEXT - EVENTS FILE TO DETERMINE THE NEXT EVENT. IF ANOTHER ARRIVAL EVENT IS TO OCCUR, SUBROUTINE ARRVL WOULD BE CALLED. HOWEVER, LET US ASSUME THAT A SERVICE COMPLETION IS TO OCCUR, IN WHICH CASE SUBROUTINE SERVCOM WILL BE CALLED.



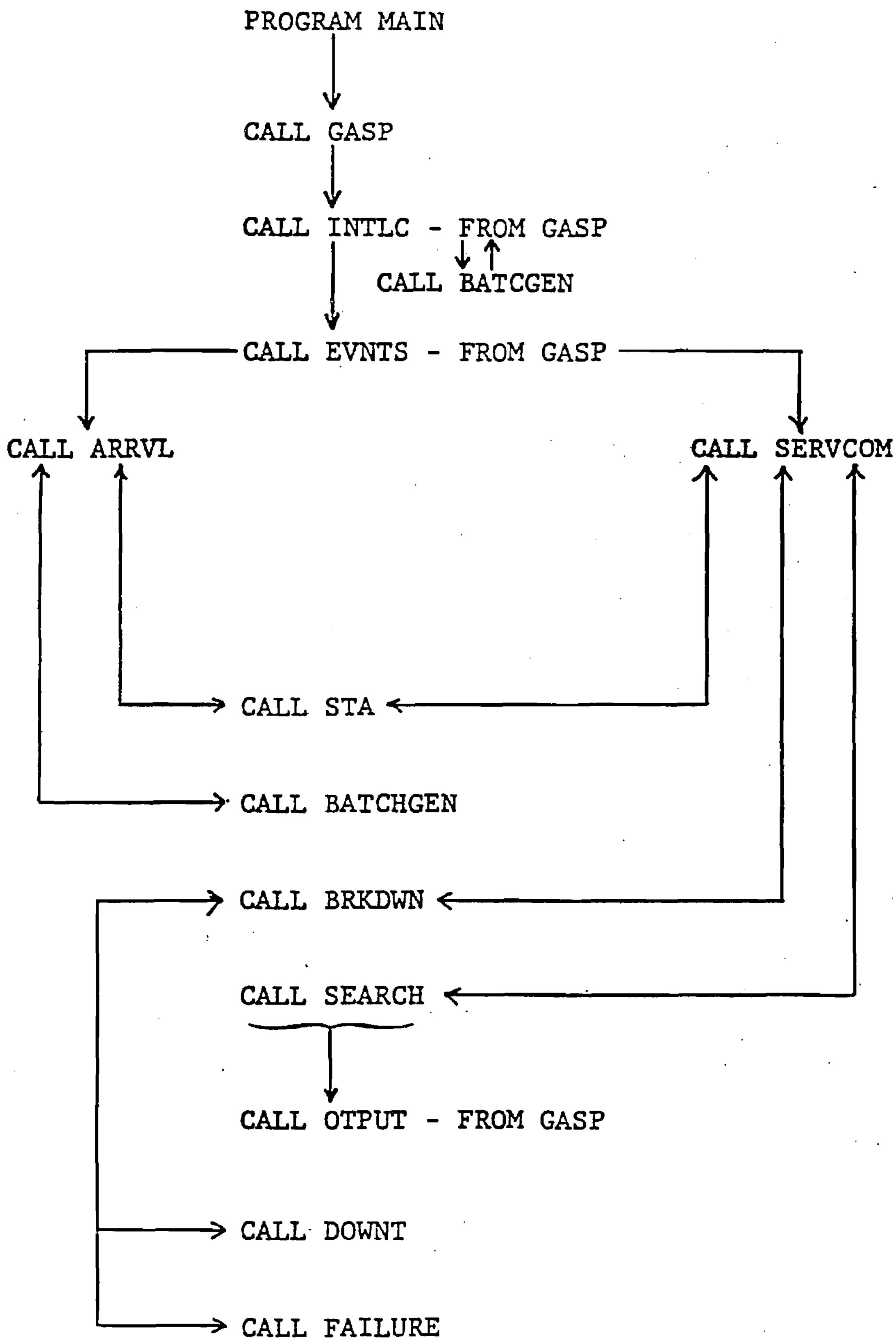
THERE ARE MORE OPERATIONS NEEDED ON THE UNIT



SUBROUTINE BRKDWN - FOR MACHINE FAILURE



OVERVIEW - SUBROUTINE CALLS FOR USER WRITTEN SUBROUTINES



AT THE END OF THE SIMULATION, GASP CALLS SUBROUTINE OTPUT, AND USER SUMMARY STATISTICS ARE COMPILED. AFTER OTPUT IS CALLED, GASP CALLES INTERNAL ROUTINE SUMRY, WHICH PRINTS GASP SUMMARY STATISTICS, AND ENDS THE SIMULATION.

E-24-686

An Assessment of Group Technology as it Relates to Plant Layout and Material Handling

Submitted to

Research Triangle Institute

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Introduction

In 1963, group technology was described as "a new idea which may well be the most important economic discovery of the century ..." (1).

Today group technology has evolved as an accepted manufacturing management technique and philosophy. Companies such as General Electric, General Motors, Deere, and Ingersoll-Rand are using the techniques of group technology to improve productivity. However, adoption of group technology in the U.S. has been slow, and the U.S. lags far behind Europe and Japan in its use (2).

This paper will examine group technology, identify the benefits and problems associated with its implementation, and evaluate its impact on plant layout and materials handling.

What Is Group Technology?

Group technology is generally defined as a technique or philosophy for small lot or batch production which is based on the grouping of similar parts or components into families and the grouping of machines into work centers to take advantage of the economies of line flow (3). This definition has many interpretations, however. Some authors define group technology synonymously with group layout and cellular production methods (3). Some include a requirement for a formal classification and coding system for grouping parts. (4) Others interpret group technology as a broad-based planning philosophy covering all areas of the manufacturing process including engineering design, material management and purchasing, process planning, production control, and cost management (5).

One definition that is often quoted was given by Professor V. B. Solaja of the Institute of Machine Tools, Belgrade, Yugoslavia. It is:

"Group Technology is the realization that many problems are similar, and that, by grouping similar problems, a single solution can be found to a set of problems thus saving time and effort" (6).

Features of Group Technology. Professor J. L. Burbidge of the International Centre for Advanced Technical and Vocational Training in Turin, Italy, identified the three key features which characterize a successful GT application as:

(1) group layout,

(2) short cycle flow control, and

(3) a planned machine loading sequence (3).

Group layout requires the grouping of machines into work centers or cells in such a way that a family of parts is processed by one machine group. In addition, each machine group is associated with a team of workers.

Short cycle flow control, or period batch control as Burbidge defined it, is similar to Materials Requirement Planning. Sales forecasts and production programs are established at short regular intervals; component and materials requirements are calculated by "explosion" of the production program (3).

A planned, rather than random, machine loading sequence takes advantage of the similarities of parts to reduce machine set-up times (3).

Classification and Coding. Another feature which is included by some authors is a classification and coding system used to group parts and components into families and to give each part a unique identifier. Although there are more than 100 classification systems in existence today (7), there is disagreement as to whether a formal classification/coding system is an essential prerequisite for the successful implementation of group technology (5). Some (5,8) believe that an overemphasis on a classification/

coding system may increase the difficulties incurred in implementing GT within an organization.

Burbidge promotes production flow analysis as a better method for defining families and groups than classification and coding in the early stages of implementation of a GT system. He recognizes the importance of a classification/coding system in the later stages of implementation, however, and also notes these other benefits from a classification/coding system:

(1) information retrieval,

(2) variety reduction,

(3) finding components for composite parts and tooling families,

(4) finding the optimum machine scheduling sequence,

(5) tooling development (3).

Many agree that a well designed classification system is necessary for forming families and groups. There are two main types of classification systems. A graphics classification system is based on the geometry or shape of the part (design features); a manufacturing oriented classification system is based on processing requirements (manufacturing attributes). An advantage of the graphics based system is that it enables the design engineer to eliminate some new part designs. Manufacturing oriented systems, which are similar in purpose to Burbidge's production flow analysis, aid more in the formation of families (9).

Candidates for GT Applications. Some general parameters have been suggested for determining whether a company is a candidate for group technology. The company should have the following characteristics:

(1) production batches of 1-5000 parts,

(2) machine shop in which general purpose tools predominate,

(3) personnel experienced in the use of computers,

(4) minimum annual sales of $5-10 million, and

(5) willingness to experience change (2).

Advantages of Group Technology

Burbidge states that the three key features - group layout, short cycle flow control, and a planned machine loading sequence - can generate "significant savings" when used together; none of the three generates major savings on its own (3). Some of the savings identified by Burbidge are shown in Table 1.

Another important area for savings is that of component design, resulting from the use of a classification/coding system (9).

Associated with these savings are the benefits of improved information retrieval, improved tool utilization, and improved productivity through job enrichment (2). Quality may also be improved with group technology. Since each team is responsible for a family of parts, team members are more familiar with a part when changeovers are made or when new parts are introduced into the family. Less scrap and rework are the results (1).

Some examples of savings which have been cited for different firms include savings of:

66%	in set-up times,
50-60%	in planning tooling,
50-90%	in tooling, and
44%	in inventories (3).

Table 1. Savings from the Implementation of Group Technology (3)

Savings due to Planned Machine Loading Sequence

- Reduced set-up times resulting in increased machine capacity and a reduction in tooling investment.

Savings due to Short Cycle Flow Control

- Reduced material obsolescence by ordering parts in product sets.
- Reduced inventory.
- Reduced scrap (processing families together often allows taking advantage of material off-cuts).

Savings due to Group Layout and Teams

- Reduced throughput time since continuous transfer between machines is possible.
- Centralization of responsibility (greater quality and cost accountability is possible when each team is associated with a specific family of parts).
- Reduced materials handling and simplification of paperwork associated with movement of parts.
- Reduced investment per unit output since group layout requires less space.
- Reduced indirect labor (clerks, dispatchers).
- Improved human relations through teamwork.
- Reduced co-ordination between foremen of different departments.
- Greater flexibility since a worker may be required to operate more than one type machine within the group.

Although savings in space, time, and investment may be obtained by the application of group technology, the major benefit may lie in the approach to planning which GT requires. The implementation of group technology requires improved process planning and an understanding of the total manufacturing system. A summary of the uses and benefits of GT in areas other than the manufacturing unit are shown in Table 2 (9).

Disadvantages of Group Technology

Much has been written concerning the advantages of group technology and the extraordinary savings achieved by some firms. However, there are several problems which must be considered.

Implementation costs and time frames are a major area of concern (10). The cost and time required for such a radical change in layout, planning, and philosophy is great, and the benefits may not be obtained immediately.

One of the most critical problem areas is the acceptance of the new technique. The major thrust of some features of GT is to eliminate waste, e.g. in the design of new parts. Resentment may be generated by the implication that the current system has unnecessary waste (9). Also, the uncertainty of change can create stress in an organization.

Another problem area concerns the new training and supervisory requirements. Under traditional batch layout, each foreman is generally responsible for operations with one machine type only, e.g. either milling machines or lathes or grinding machines. But with GT, the foreman is responsible for all machines required to produce a family of parts. The foreman may require new training in order to supervise effectively under GT. Likewise, a worker may now be required to operate more than one type of machine. While this increases flexibility, it also requires additional training and

Table 2. Applications of Group Technology (9)

Engineering

- Design retrieval
  - Reduce number of new drawings
    - Reduce number of new parts
    - Fewer records, ECN's etc.
- Cost-reduced designs
  - Design around 'Least Cost' parts
- Rationalize design
- Identify preferred parts
- Establish need for value analysis
- Failure analysis
- Establish specifications
  - Finishes
  - Tolerances
  - Heat treatment
  - Optimum design
- Improved project scheduling
- Improve prototype cycle
  - Modify similar parts
  - Increase Model Shop productivity through Group Technology
  - Use existing tooling
- Eliminate duplicate parts
- Reduce number of similar parts
- Reduce design costs

Industrial Engineering

- Improved cost reduction program
  - Value engineering by 'Family'
- Reduce N/C programming time
- Define N/C tool requirements
  - Optimize capital expenditures
- Provide comparison of cost centers
- Improve facilities planning
- Improve production forecasts
  - By department
  - By machine type
- Reduce number of operation sheets
  - Utilize least-cost process
  - Utilize proven processes
- Improved cost estimating
- Shorten implementation cycle
- Provide for Group Technology
  - Improve machine loading
  - Rational planning procedures
  - Reduce setup time
  - Reduce overall production time
  - Reduce work in process
  - Improve MTM studies
- Provide basis for material handling studies
- Provide basis for off-loading decision

Corporate

- Worldwide and Interdivisional
  - Design interchangeability
  - Cost analysis
- Comparison of proprietary and competitive products
- Reduction in
  - Work in process
  - Inventory
- Rationalize capital expenditures
- Interchangeability of decimal and metric information on
  - Drawings
  - Tools
  - Materials
  - Components
  - Process sheets
- Accurate estimates on
  - Component costs
  - New product costs
- Improve capital equipment utilization

Table 2 Con't

Production Control

- Improve inventory identification
  - Parts in process
  - Finished stores
- Identify acceptable substitutes
  - Increase 'Make-from' lots
  - Increase parts utilization
- Minimize reworking
- Reduce inventory
  - Raw material
  - Parts in process
  - Finished parts
  - Tools
- Economic disposition of
  - Surplus
  - Excess material
  - Defective parts
  - Improve MRO usage

Quality Control

- Failure mode analysis
  - Reduce inspection time
  - Sample larger lots
  - Sample fewer designs
- Improve gage control
- Improve gage utilization
  - Fewer gages
  - More universal gages
- Rapid identification of similar procedures

Tool Design

- Reduce number of designs
- Reduce number of tools
- Reuse obsolete tools
- Provide basis for universal tool
- Improve scheduling of tools

Purchasing

- Reduce number of purchase orders
  - Blanket orders
  - Larger lot sizes
    - Materials
    - Commercial parts
    - Supplies
- Available information on
  - Suppliers' performance
  - Competitive costs
  - Best price and delivery
  - Interplant price comparisons
- Acceptable substitutions
- Reduce unit costs

Service

- Identify unknown parts
- Assist in costing new service parts
- Find replacements efficiently
- Aid in determining substitutes
  - For competitive products
  - For out-of-stock parts

raises the question of compensation. The current wage system may require a redesign since workers are now operating more than one type machine, thus increasing their job responsibility (10).

The rate of change of the product mix may also be a source of problems (10). If a firm practices group layout, must the firm change the layout every time the product mix indicates that a new group is needed? Or should the firm use group layout at all? Often, even the initial rearrangement into groups carries a heavy cost which may not be justified (2).

Another problem is the difficulties associated with out-of-cell operations. Often, special and expensive materials handling procedures are required to handle out-of-cell operations (10). If a machine is added to a group to accomodate the operation within the cell, the machine may be under-utilized; or the machine may be needed by another cell, and the problem of intercellular flow reoccurs.

Machine balancing may be complicated, especially with a rapidly changing product mix. One of the advantages of GT cited by Burbidge is reduced throughput time due to reduced handling and transportation between operations. In some cases, however, the transportation time results in better machine balancing, and the handling device is needed for in-process storage.

Another possible problem occurs when teams of workers are too large or too small. The optimal team size is six to twelve workers (6). Too large a group may create problems of control for the foreman; too small a group may allow personal conflicts to interfere with productivity.

Impact of GT on Plant Layout and Materials Handling

Plant Layout. A major question which affects plant layout is whether group layout is an essential component of group technology. Burbidge supports the idea that total benefits cannot be obtained without group layout. However group layout is associated with several difficulties including balance of labor, machine utilization, and the need for different skills for both operators and supervisors as discussed previously.

Group layout is reported to provide the benefits of reduced throughput time and reduced in-process inventory, improved scheduling, and greater productivity through job enrichment and teamwork (9).

Given machine groupings, the following considerations must be resolved for group layout:

(1) the optimal arrangement of machines within groups,

(2) the optimal arrangement of groups within the plant,

(3) the materials handling requirements for (1) and (2), and

(4) the materials handling requirements for out-of-cell operations.

Computerized layout methods such as CRAFT or CORELAP (11) might be used to help in layout of machines within groups or groups within the plant independently. However, there is currently no layout technique which addresses all four planning areas. Carrie (12) has developed a procedure using aggregate flows to determine the layout of multi-product lines (layout within groups). Shunk has studied the grouping and layout of machines within the plant to optimize control. For one installation, he found that a hybrid layout was optimal; the hybrid included both GT cells and a job shop center (13).

Because of the expense of the initial change in layout and the need for relayouts caused by changing product mix, some do not include group layout as a requirement for a successful GT application. Hitchings presents a method of analyzing efficient layouts and the cost of relayout vs. inefficient layout (14). This approach might be used to determine whether group layout is appropriate for a particular firm.

Materials Handling. With group layout, most authors assume that there is little or no flow between machine groups, thus resulting in savings in materials handlings (3). Savings also arise within groups since similar parts are likely to use the same materials handling equipment (15). However, savings projections are often based on savings in distance. In some cases the number of handlings is more important than the distance that the material is moved (14). Also conveyors and automatic guided vehicles have increased the distance insensitivity of handling. These inconsistencies may discount some of the savings attributed to group layout and reduced handling. However, little research has been conducted in this area.

Areas for Research

Several areas which need further study have already been discussed. These include:

(1) development of a method to determine the cost effectiveness of group technology. In a study of techniques used for evaluating group technology, Grayson (16) found that there had been little research in the field. Most of the approaches that he discussed were from Soviet papers which presented methods which "have little to commend themselves to the practitioners of group technology but, on the other hand ... provide a useful bench mark."

(2) development of a computerized layout approach for GT.

Other areas of research which have been suggested include:

(1) the proper sequence of implementation for all aspects of GT, e.g. should a classification/coding system be implemented in the early or later stages (17),

(2) the impact of GT on robotics, automatic identification and flexible production facilities (18).

Issues relating to materials handling which need further investigation were identified at an NSF sponsored workshop in January, 1979. These issues are:

(1) system impact, i.e. multiple viewpoints,

(2) intercellular and intracellular movement,

(3) material flow classification systems,

(4) evaluation techniques and algorithms for systems design (19).

Conclusion

Group technology is a manufacturing technique and philosophy which can bring large savings to the aerospace industry. However, many of the problems associated with the implementation of GT have not been adequately studied. Further investigation of these problems and the areas for research identified in this paper will help the full potential of group technology to be realized.

A major concern for the ICAM Program is the adoption of Group Technology as the basis for layout and material handling. The benefits of GT to process planning are well understood. However, the impact of GT-based layouts on work-in-process storage, control, space, equipment, and personnel requirements is not well understood. Alternative scenarios must be developed and evaluated to insure that GT gains in planning are not off-set by the handling, storage, and control system.

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A REVIEW OF MATERIAL REQUIREMENTS PLANNING SYSTEMS

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INTRODUCTION

The primary purpose of the following report is to review some of the fundamental concepts and problems in Material Requirements Planning (MRP) Systems. Even though MRP has existed as a concept for a considerably long time, only quite recently the subject has received significant attention. One basic cause for the sudden development in the field of MRP is technological advances made in data processing capabilities. With todays computing equipment it has become both time and cost feasible to implement such systems even in a major manufacturing company that can produce up to a thousand end items.

However, as various authors point out, not all MRP systems are successful and some do not operate efficiently. At first glance, such failures may be thought to be related to software problems and/or computational constraints. Obviously part of it is in fact related to the above, but a significant portion of the problems arise because the user does not fully understand the principles of MRP Systems. It is interesting to note that, the basic principle of MRP Systems (as will be discussed later) is very simple. Then, what is it that the user fails to comprehend? Why are failures reported even though the principle is trivial? The answer to such questions is not straightforward. However, some basic reasons for failure in effectively using MRP Systems can be summarized as follows:

1. The system has a multi-level structure. The user generally fails to realize that a set of seemingly "good" decision rules implemented at any intermediate level may have adverse effects on

lower levels. It is generally hard to predict the impact of a given policy at a specific level on lower levels (or with the same token on higher levels). The lot sizing problem is a typical example. Various simulation studies have been done to better understand such interrelationships. Various studies performed in this area will be presented later.

2. The user fails to realize the importance of data accuracy. Inventory files are not debugged either properly or frequently enough. The bill of material (which is a very important component of the MRP System) is not up to date, contains errors, or with its present structure is not suitable to be used in such systems. The user should always keep in mind that he is dealing with highly computerized procedures, and no matter how unreasonable some of the data entries are, the computer is not clever enough to detect them. Hence, a valid bill of material and clean, up-to-date data are essential ingredients for an usable MRP System.

3. Unrealistic lead times: One important feature of MRP Systems is their ability to assign priorities to orders and update them as necessary. Failure in estimating and updating lead times accurately will cause the informal system to take over, i.e. manual hot lists that are not communicated through the MRP System, thereby virtually abandoning the basic spirit for having such systems, i.e. formalizing the informal system.

The above factors are by no means exhaustive. However, many of the problems seem to relate directly or indirectly to above mentioned problems. For instance, several techniques are available for solving lot size problems. But almost all of them are concerned with minimizing a cost function (usually inventory carrying costs plus ordering costs) which totally ignore the previously mentioned multi-level structure of the system. There also exists numerous techniques for scheduling orders, but schedules will not be realistic if priorities are not assigned accurately and timely. However, priorities are based on due dates and lead times, where lead times are a function of queue times (aside from set-up and processing times which are relatively easier to estimate). But the queue time for a specific order depends on the priorities assigned to the rest of the orders as well as the particular lot sizing technique(s) used. Thus, it is not a simple matter to design and operate such systems at a global optimum basically due to above addressed interrelationships. Other problems and corresponding techniques to solve some of them will be discussed in the following section.

LITERATURE SEARCH

As indicated earlier, quite recently considerable effort has been given to improve and better understand the design and operation of MRP Systems. Research in MRP Systems tends to fall within the following areas: development of efficient and flexible structures for the bill of material, accounting for unexpected demands and development of techniques for efficient rescheduling, analyzing the combined effect of different lot sizing and scheduling techniques, and finally those studies aimed to improve over-all effectiveness by taking a global approach to the system and its environment.

Development of efficient and flexible structures for the bill of material:

An important distinction between Order Point systems (Statistical Inventory Control) and MRP systems lies in the fact that the order point/order quantity approach is part based, while MRP is product oriented. Order point views each inventory item independently of all the others, while MRP looks at the product and the relationships of its components, through bills of material. A significantly useful paper for structuring the bill(s) of material is presented by Orlicky, et. al. in (10). They provide a seven-point checklist that will help spotting structural deficiencies in the bill of material. The topics they cover in (10) include: assignment of identities (elimination of ambiguity, levels of manufacture); modular bill of material (disentangling product option combinations to avoid unnecessarily high numbers of bills of material, segregating common from unique parts); and lastly pseudo-bills of material.

For proper assignment of identities three requirements are provided as: 1) Each individual item of inventory covered by the MRP System should be "uniquely" identified. This includes raw materials and subassemblies, 2) An identifying number should define the "contents" of the item uniquely, unambiguously. The same subassembly number must not be used to define two or more different sets of components, and 3) Bill of material should reflect the way material flows in and out of stock, where "stock" does not necessarily mean "stockroom" but rather a state of completion. The bill must define the product structure in terms of so-called "levels of manufacture", each of which represents the completion of a step in the buildup of the product.

The authors also address another problem in assigning identities, namely, identifying those items that are "immediately" consumed in the assembly of their parent items. The problem arises because the logic of MRP assumes that each component item goes in and out of stock. Such items do not require separate identity in the bill of material, provided there is never an over-run, a service part demand, or a customer return. Otherwise, it must be separately identified in the bill and item records must be maintained. For such items, it is suggested in the paper that a "phantom bill" is used to eliminate the requirement of reporting of all transactions for the system to post these and keep the records up to date. Details related to the implementation of the "phantom bill" technique are given in (10) with examples.

The second topic covered in (10) is modular bills of material. The process of modularizing consists of breaking down the bills of high-level items (products, end items) and reorganizing them into product modules. The basic motivation in modularizing bills of material is to keep the number of bills of material at a reasonable level in cases where the end item has a high number of options. Instead of maintaining bills for individual end products, under this approach the bill of material is restated in terms of the building blocks, or modules, from which the final product is put together. However, we still have to control the production of those end products that do not have a bill of material under this approach. Hence, as a result, we retain the bills for end items, now referred as manufacturing bills, or M-bills. M-bills are not involved in the process of component requirements planning. They are used for purposes of assembly only.

The third and last topic covered in (10) is pseudo-bills of material. The need for pseudo-bills arises when one uses modular bills of material. That is, when the bill is broken down in the process of modularizing, various assemblies are promoted and become end-items, i.e. highest level items with no parent. This tends to create a large number of end items; and forecasting becomes tedious. A simple solution to the problem is to create an artificial parent for each group and a so-called pseudo-bill for each parent. (Pseudo-bills are also referred to as super-bills or S-bills). These newly created bills, along with the M-bills presented earlier are sometimes collectively called the super structure. The authors conclude the paper by mentioning the possibility of adding indirect material to the bill of material which will ease inventory control for such materials.

Accounting for unexpected demand and development of techniques for efficient rescheduling:

Unplanned demand and errors in the master schedule may dictate rescheduling quite frequently. To explode all the bills of material each time a schedule change occurs will generally be costly, if not time infeasible. One technique to avoid such costly reschedules is the "Net Change MRP". The basic difference between Net Change MRP Systems and ordinary MRP Systems (usually referred as "regenerative MRP") is that, the Net Change MRP explodes only those bills of material that are affected by the error and/or unexpected demand. Hence, replanning is done only for those components that appear on above mentioned bills of materials. As a result, Net Change MRP is a potential time and money saver; however, there are some drawbacks associated with such systems. Following authors have discussed and analyzed various issues related to rescheduling.

In (12), Orlicky presents the concepts of Net Change MRP Systems and he presents the characteristics, advantages and disadvantages of such systems. One major design question raised for MRP Systems is the "frequency" of the requirements explosion, how often is it "practical" to re-explode and replan requirements? In an ideal system replanning should be taking place continuously according to this author. However, it is not clear how continuous planning should be implemented because "classical" MRP Systems are based on so-called periodic schedule regeneration. As an alternative the author suggests Net Change MRP Systems because under the classical (regenerative) MRP System:

1. Every end item requirement stated on the master production schedule must be exploded.

2. Every (active) bill of material must be retrieved.

3. Every (active) inventory item record must be recalculated.

4. A high volume of output is generated and documented.

Hence, the frequency of schedule regeneration becomes an important issue representing a trade-off between above listed factors and the timeliness of the system (infrequent planning will cause the system to be outdated). Thus, time saving techniques such as Net Change MRP gains importance.

According to the author, a Net Change MRP System can be implemented for either of the following two modes of use:

1. High frequency replanning (typically on a daily basis).

2. Continous, or on-line, replanning (a transaction-driven system).

Regardless of mode of use, the logic of planning and time-phasing material requirements is essentially the same for both regenerative and Net Change systems, except for

1. The treatment of the master production schedule

2. A "partial" explosion of requirements

Under the Net Change approach the master production schedule is viewed as one plan in continuous existence rather than as successive versions or issues of the plan and (the schedule) can be up-dated at any time by adding or subtracting the net difference from its previous status. The author continues the paper by giving an example for partial explosion mentioned above. Partial explosion is the key to the practicability of the Net Change concept, as it minimizes the scope of the MRP job at any one time, and thus permits a high frequency of replanning.

The author provides the following list as the advantages of Net Change MRP Systems:

1. The requirements planning (explosion) job at schedule release time is minimized.

2. Makes it possible to process schedule changes occurring between release cycles.

3. It enables the system to be independent of the timing of both releases and changes; and to be continually up-to-date.

4. The system can generate non-delay outputs (thus communicating the need for inventory management action at the earliest time possible).

Despite the advantages of Net Change MRP Systems, there exists various drawbacks. Orlicky emphasizes the following:

1. The relative processing inefficiency of Net Change, i.e. from a data processing point of view Net Change Systems are more involved. However, it should be kept in mind that the goal is requirements planning efficiency and not data processing efficiency.

2. The "nervousness" of the system. Since the system is continuously updating itself, it is also continually replanning, and thus revising order action. This may cause a stream of constant revisions of open orders, both in the shop and those previously placed with outside suppliers. (There are studies done to overcome the nervousness and to make it productive rather than destructive. One of them (16) will be discussed later.)

3. Reduced self-purging capability, and the consequent need for stricter external disciplines. With the classical regenerative system, the old plan is literally thrown away every time a new version of the master production schedule is authorized. This has the advantage of throwing away old errors, plus data that become invalid due to change, along with the old plan. With Net Change, on the other hand, the old plan is retained and merely modified and/or updated. Old errors never fade away, and changes in the bill of material, lead times, and in other parameters of the system must be methodically incorporated, as they occur. Furthermore, the discrepancies between "planned" and "actual" are carried forward and their cumulative effect will gradually render the system ineffective. As a result, companies that use Net Change MRP maintain a stand-by program for requirements regeneration, to be substituted for the Net Change program if and when the system's records accumulate too many errors.

Orlicky (12) concludes his paper by mentioning the future of Net Change MRP Systems. In his opinion the future belongs to Net Change MRP Systems due to its several advantages and its superiority over classical, regenerative MRP systems.

Another paper that is concerned with the improvement of MRP systems in terms of handling unplanned demand and master schedule errors is presented by Eichert (6). He points out that the key element in developing a solution technique for above mentioned problems is to recognize that most unplanned demand and master schedule errors may be treated as independent requirements. (Recall that, so-called independent requirements (demands) are those requirements that have to be forecasted, for they can not be determined by exploding the bill of material.) One technique to anticipate production delays and, under some conditions, to alter schedules is pegging. Basically, pegging is a tool which relates a given requirement to associated end items, components, etc. It may take various forms like end-item pegging, single level pegging, etc. Papers written on pegging will be discussed later.

The impact of unplanned delays and errors depends on the bucket size. The time spans employed for time phasing and requirements collection are called buckets. Generally, a week is the largest bucket size acceptable in a good MRP System. Small internal buckets are essential to prevent excessive lead time inflation. Small bucket size will minimize lead time inflation, maintain relative priorities, and help reduce inventory costs. The use of small buckets will improve reaction to unexpected demands; however, they will do little to anticipate these requirements. Recall that the justification for regeneration and net change is to maintain priorities up-to-date. The necessity for frequent regeneration or net change in the absence of Master Schedule alterations may be an indication that unplanned demands are hampering the MRP System. Eichert's paper (6) is basically concerned with planning such unexpected demands to incorporate them into the MRP System. He presents a good list for liabilities which are not included in most Master Schedules, and various methods to incorporate each into the system. Finally, he suggests a simple technique to predict unplanned demands. It basically consists of forecasting the average and mean absolute deviation of the difference between planned and actual demand figures using exponential smoothing. Then the forecasted amount is incorporated to the Master Schedule by considering it like a dependent demand.

The above approach suggested by Eichert is a useful technique; however, in presenting the approach he overlooks one factor, namely, the safety stock levels at the time the forecast is being made. If the forecast is not adjusted through current safety stock levels the company may end up carrying excessive inventory in their safety stock. Of course, exponential something will eventually adjust the forecast if they are being over-estimated in the last few periods, but until that time safety stocks will be already inflated. Hence, incorporating safety stock levels at the time of the forecast most probably will improve his approach.

Another paper concerned with rescheduling in MRP Systems is presented again by Orlicky (11). He analyzes the rescheduling of two types of orders, namely, the shop orders and purchase orders; both within the framework of Net Change MRP Systems.

He points out that with tomorrow's Net Change MRP System it will be possible to plan by date rather than by bucket, and that most users will aim at replanning once a day. As a result the volume of orders to be rescheduled over a given time period will be considerably higher. In rescheduling shop orders, Orlicky presents the three principle concerns as follows:

- frequency of rescheduling
- trivial reschedules
- rescheduling to an unrealistic due date

The importance of rescheduling frequency was indicated earlier. In the context of rescheduling shop orders, frequent rescheduling should not disrupt shop operations, as changes in operation dates and in relative priorities of work pertain primarily to jobs not yet started. Rescheduling means revising and updating information. The second concern, namely, trivial rescheduling is used when due dates are changed by a small time unit like a day. Orlicky notes that the MRP System user should not constrain the system's rescheduling ability based on criteria of "triviality".

The third and last concern, i.e. rescheduling to an unrealistic due date is discussed in depth by Orlicky. Obviously various safeguards are needed against unrealistic schedules. In a Net Change MRP System unrealistic due dates are strictly undesirable. While such a date may correctly reflect early need, and indicate the proper relative priority of the order, the fact that the date cannot and will not be met invalidates the dates of need (and due dates) for co-component orders whose priorities are dependent on the availability of the item with the unrealistic due date. Orlicky presents various techniques that can be used against automatic rescheduling to unrealistic dates.

One technique is to use a dual lead time. In addition to the normal lead time used by the system for offsetting planned order releases, another, "minimum lead time" value is supplied by the user. Very similar to the dual lead time technique, there exists the use of "earliest feasible due date". Another technique is called "firm open order" where only the due date, not the order quantity, is subject to being made firm by the planner. Lastly, one can use the "execution-level constraint" to guard against unrealistic due dates. Under this approach, the Net Change MRP System would reschedule shop orders freely, in accordance with the respective dates of need. The new due dates would then immediately be processed by an operations scheduling system which would determine whether there is enough time left to complete the remaining operations by the due date indicated by the MRP System.

As mentioned earlier, Orlicky also discusses rescheduling of purchase orders. Among the three concerns discussed above (rescheduling frequency, trivial rescheduling and unrealistic due dates), only the first two are legitimate and the third one does not apply. It is clear that, unlike shop orders, purchase orders cannot be rescheduled everyday. Orlicky suggests a weekly update of the sequence of need (priority) for all the orders placed with a given vendor, and the revision of desired delivery dates. Note that such an approach requires the MRP System to be capable of tracking every purchase order down to the vendor.

Unlike shop orders, there are trivial reschedules of purchase orders which should be avoided. It is difficult to say, however, precisely what kind of divergence is significant and what is trivial. Generally speaking, the significance is a function of:

- magnitude of divergence (the difference between date of need and due date)

- direction of change (needed earlier or later)
- distance in time (how far out in the future)

To deal with the special problems of purchase order, Orlicky suggests the use of a time fence constraint. This technique defines only a portion of the planning horizon, measured from the current date forward, beyond which changes in dates of need are ignored by the system. One drawback of this approach is that, it will fail to reschedule those orders beyond the fence no matter how significant the difference between the date of need and due date is. Orlicky refines his suggestion by providing a better solution to the problem. That is, do not implement a "programmed" rescheduling time fence constraint at all. Instead, continuously monitor the dates of need and due dates and print action messages based on a test of significance.

Orlicky concludes his paper by providing a test of significance. Obviously, any test should be somehow based on those variables addressed earlier, i.e. magnitude of divergence, direction of change, and distance in time. The following formula is provided:

$$\frac{A}{B} \geqslant 0.1$$

where A = divergence
B = distance
0.1 = constant (in above formula, 10%) specified by the user.

There exists another ratio, namely, the critical ratio which is similar to the above ratio provided by Orlicky. The critical ratio is used for assigning proper priorities in the process of rescheduling (replanning). Wassweiler (17) has written a paper on the effectiveness of the critical ratio. The technique of the critical ratio consists of expressing the relative priority of work in process by relating the time remaining before an item is due, to the amount of work remaining. For example, if a part in process is required in five days and it has ten days of work remaining, the critical ratio will be 0.5 (5/10). Ratios of 1.0 mean the job is exactly on schedule, and anything less than 1.0 means behind schedule. Wassweiler points out that the difficulty with critical ratio occurs with the "time remaining" element of the ratio. He cites the real problem as the integrity of the due date. Furthermore, when all the orders are past due time remaining will be zero for all orders. Wassweiler suggests that if one allows negative values to be used for the time remaining element, then we will have negative ratios which still will reflect relative priorities.

In discussing the effectiveness of the ratio Wassweiler overlooks a very important characteristic of the ratio. As mentioned earlier the ratio is applied to those orders already in process. Hence, to be really effective such a ratio has to consider set-up costs and/or set-up times. In an environment where set-up times are reasonably long, using the critical ratio in its present form may cause a total disaster.

So far we have discussed techniques for efficient and prompt rescheduling in MRP Systems. There still exists, however, another issue concerning rescheduling, namely, the "nervousness" of the system. A "nervous MRP" System can be defined as one that generates excessive changes to low-level requirements when there are no major changes in the master schedule. Steele (16) presents a paper on how to handle the nervous MRP System. He states that changes in low-level requirements can be traced to six causes:

1. Master Schedule Changes: Any change to the master schedule will be exploded through to many low-level items. Due to lot-sizing even minor time-phasing changes can be amplified at low-levels. (Lot size amplifying will be discussed in more detail later.)

2. Unplanned Demand: How to incorporate unplanned demand to the master schedule has been discussed earlier.

3. Allocation Not Issued in Expected Quantity: Whenever actual demand for a component does not equal the expected demand (plan), the need date of the replenishment requirement will immediately be effected. Bill of material errors and/or inappropriate units of issue could be obvious causes.

4. Order Released in Unplanned Quantity: Has a similar impact as cause three above. This cause cannot be always eliminated. Its existence depends on how well the people using the system understand the importance of meeting the plan.

5. Order Released Prematurely: This causes all subordinate (co-components) requirements to jump from a future period to the current period. The planner should not arbitrarily release orders early without recognizing the implication of unexpected earlier requirements at the subordinate level.

6. Parameter Changes: A change in a system parameter, such as lead time or safety stock level, will also generate changes at lower levels.

Among the above listed six reasons, Steele (16) analyzes the first, ie. master schedule changes within the framework of lot-sizing amplification; ie. small changes at any given level cause dramatic changes in the requirements for lower levels due to lot-sizing. Obviously, the relative impact depends on the particular lot-sizing technique utilized. Steele provides an example under the period order quantity (POQ) lot-sizing.

The impact of lot-sizing nervousness can be dampened by using a fixed order quantity as the lot size. All the advantages of discrete lot-sizing will be lost, but if changes are occurring frequently, orders matched exactly to requirements would be temporary anyway. Steele claims that using fixed order quantity will bring stability since it does not pass quantity changes through to lower level items. He also points out a shortcoming of the fixed order quantity; stating that it may become an uneconomic quantity under a revised master schedule, or it may over order a part with declining usage. Hence, the appropriateness of the quantity should be reviewed regularly.

Steele concludes his paper by a list of suggestions for damping nervousness; namely,

- Minimize causes
    - (a) Reduce or dampen minor master schedule changes
    - (b) Reduce or dampen unplanned demand
    - (c) Follow the plan with respect to allocations, order quantities, and order release timing
    - (d) Control parameter changes
- Use pegging: Being able to peg-up to parent levels can be very useful in placing orders and in avoiding unwarranted major priority changes.
- Stabilize lot-sizing: If nervousness remains after minimizing causes, consider the following policy:

  Top level - Use fixed order quantity

Intermediate level - Use fixed order quantity or
lot-for-lot ordering

Bottom Level - Use period order quantity
(Above policy is also suggested by various other authors.)

- Use firm planned order

Berry (4) presents a paper on the impact of changes in lead times and production lot sizes on system performance. He expresses the performance of the system by the following five measures: manufacturing flow time mean and variance, work-in-process inventory, finished item inventory, and the level of customer service. He also presents effective operating strategies for setting lead times and production order quantities when customer service and inventory levels are used as the performance criteria. He defines the customer service level as the percent of the demand for an end product item that can be delivered immediately from the finished goods inventory to satisfy customer demand.

His approach basically consists of measuring the five performance measures mentioned earlier after simulating the system by varying lead times and production order quantities (one at a time or simultaneously). After obtaining the simulation results he constructs regression lines to express the relationship between the performance measures (the dependent variable) and lead times and order quantities (the independent variables). Throughout the study he analyzes the performance effects on component and end product items. For scheduling the orders he considers two alternatives: the critical ratio and the shortest processing time (SPT) rule.

Berry presents the results for the component items and end product items separately. For component items he shows that the performance impact obtained by changing the component item planned lead times is highly dependent on the shop scheduling procedure employed. Under the critical ratio scheduling an increase in the component item planned lead time produces:

- An increase in the average manufacturing flow time and the work-in-process inventory level for components,
- A reduction in the manufacturing flow time standard deviation for components,
- An increase in the finished component inventory.

He does not observe the same effects under SPT scheduling. He explains the difference in performance between critical ratio and SPT scheduling by the fact that the critical ratio rule considers due date information while the SPT rule does not.

He also shows that (except for an initial reduction due to increased effective shop capacity) the flow time will increase as the order quantity is increased due to increasing machine processing times.

For the end-items (assembly items) he presents the following results:

1. Changes in the assembly planned lead time have no impact on assembly item average flow times and the level of work-in-process inventory in assembly.
2. An increase in the planned lead time for component items reduces the average assembly item flow time as well as the level of work-in-process inventory in assembly.

Berry's work is well organized and his approach to the problem is systematic. However, his conclusions (presented above) are derived from the regression lines he constructs. Apparently, he determines the expected direction of change by looking at the sign of individual regression coefficients. He overlooks the fact that, in regression analysis, one cannot predict the direction of change by observing the sign of individual coefficients unless all independent variables are statistically independent. (By construction, Berry's independent variables are not statistically independent.)

In previous discussions, it is quite evident that pegging plays an important role in effective rescheduling in MRP Systems. It can also be used in reducing the nervousness of the system. As defined earlier, pegging is a technique which can be used to maintain traceability during the requirements planning process. Basically, pegging establishes a connection between the requirements and the exploded component records and then stores this connection so that requirements may be traced to their source. There are two types of pegging: full pegging and single level pegging.

With single level pegging, the source of requirements may be traced upward one level in the bill of material to the next higher assembly. By looking up a series of these one level pegs, the top level requirement may be found. Full or end-item pegging, maintains the connection to the top level in the requirements planning process. This makes tracing component requirements to their source much easier and allows the priority of the original detail requirement to be carried to all levels of the bill of material. However, full pegging is technically more involved. Herrick (7) presents the following as reasons that complicate full pegging applications:

1. Full pegging is in direct conflict with the commonly used MRP techniques of summarizing, lot sizing and calculating net requirements as they pass down succeeding levels of the bill of material.
2. The number of detail connections which must be stored goes up exponentially with the complexity of the bill of material, the number of end items, and the number of time periods in the horizon.
3. Running a system with end item pegging can consume enormous amounts of computer time and disk space which, even with rapid technological advances, still is not cheap.

Even though Herrick (7) reports a moderately successful application of full pegging, above difficulties still remain valid. One alternative is to use a combination of single-level and full pegging; one may call this multiple-level pegging. The literature does not indicate any work done in multiple-level pegging and the trade-offs involved in using single-level versus full pegging.

Effects of different lot-sizing and scheduling techniques:

Up to this point, we have mentioned lot-sizing and scheduling techniques within the framework of rescheduling (replanning) in MRP Systems. Berry's paper (4) which is discussed in the previous section constitutes a good example for major concerns in the lot-sizing and scheduling field. There exists papers which concentrate on the "comparison" of different techniques. One such paper is presented again by Berry (2). It deals with a comparison of four prominently mentioned ordering procedures for requirements planning systems: Economic Order Quantities (EOQ), Periodic Order Quantities (POQ), Part Period Balancing, and the Wagner-Whitin algorithm.

He initially compares the above procedures with a hypothetical example. His assumptions include: all of the requirements for each period are available at the beginning of the period; all of the requirements for any given period must be met and cannot be backordered; the ordering decisions occur at regular time intervals, eg. daily or weekly; the orders which are placed at the beginning of a period, will be available in time to meet the requirements for that period (ie. zero-production lead time which is not very restrictive because once the ordering decisions are made, they can be offset to allow for the production lead time); and finally he assumes that the components are withdrawn from inventory at a uniform rate during each period; hence, the average inventory level is used in computing the inventory carrying costs.

The following facts can be summarized from his example: under the EOQ approach, since demand used in the example does not occur at a constant rate, as is assumed by the EOQ formula, the restriction of fixed lot sizes results in larger inventory carrying costs. In addition, the order quantity must be increased in those periods where the demand exceeds the economic lot size plus the amount of inventory carried over into the period. Finally, the use of average weekly demand figure (as required by the EOQ formula) in computing the economic lot size ignores a considerable amount of other information contained in the requirements schedule, ie. magnitude of demand in individual periods.

One alternative to reduce excessive inventory carrying costs that occur under the EOQ approach is to use the EOQ formula to compute the economic time interval between replenishment orders while allowing different order (lot) sizes for each order. This approach is called the Periodic Order Quantity (POQ). Although, the POQ procedure reduces inventory carrying costs by allowing the lot sizes to vary, like the EOQ procedure it, too, ignores much of the information contained in the requirements schedule. That is, the replenishment orders are constrained to occur at fixed time intervals, thereby ruling out the possibility of combining orders during periods of light product demand.

The Part Period Balancing procedure uses all of the information provided by the requirements schedule. In determining the lot size for an order, this procedure tries to equate the total cost of placing orders to cost of carrying inventory. It also lets both the lot size and the time between orders to vary. Although, Part Period Balancing utilizes all of the information available it will not necessarily give the optimum ordering policy since it does not evaluate all of the possibilities for ordering material to satisfy the demand in each week of the requirements schedule.

Lastly, the Wagner-Whitin algorithm is presented. This procedure will minimize (optimize) the total cost (ordering cost plus inventory carrying cost). Basically, this procedure evaluates all of the possible ways of ordering material to meet the demand in each week of the requirements schedule. The penalty of using the Wagner-Whitin algorithm is increased computation time. Hence, it is not necessarily always the best procedure to use.

Berry (2) reports several papers dealing with the comparison of Economic lot size and Wagner-Whitin models. Such studies have noted that the difference in performance (measured in total cost) between these approaches depends upon the variability of the demand data. That is, as the assumption of a constant demand rate is removed, the performance of the EOQ model declines relative to the Wagner-Whitin algorithm.

In (2) Berry further elaborates on a study done by Kaimann (21).

In comparing the relative performance of the two algorithms (EOQ and Wagner-Whitin) Kaimann varies the problem parameters systematically along two dimensions: the coefficient of variation of the product demand in the requirements schedule and the ratio of the ordering and inventory carrying costs (S/C_1). Berry (2) points out that a sharper distinction can be drawn between the performance of the two procedures if the ratio of the economic order quantity to the average demand ($EOQ/\overline{D}$) is substituted for the S/C_1 defined above.

After the aforementioned substitution, Berry shows that (by using an example) the EOQ procedure leads to higher total costs than the Wagner-Whitin algorithm except when the $EOQ/\overline{D}$ ratio is less than 1.0, in which case weekly orders are placed. He shows that, in no case the Wagner-Whitin algorithm is more costly than the EOQ procedure as opposed to Kaimann.

Berry (2) concludes his paper by an attempt to compare the POQ approach to the Part Period Balancing approach. He shows a close correspondence between the performance of these two procedures and the Wagner-Whitin algorithm, but states that the data he works with is not sufficient to draw any firm conclusions.

There are two factors that Berry (2) does not take into account. The first is forecast error. He assumes that the requirements forecast remains fixed and is not subject to forecast error. He addresses the effect of forecast errors on the performance of lot sizing techniques as an important problem for further research. The second factor is the multi-level structure of the problem. That is, Berry compares the procedures as if planning is done at a single level and he ignores the impact of the results at lower or higher levels. A paper presented by New (9) is discussed subsequently and it does take into account the multi-level structure of the problem.

New points out that the effect of lot-sizing algorithms (other than lot-for-lot) at high levels is always to "lump-up" the demands for lower level items; and the more the number of levels at which lot-sizing occurs, the more "lumping" there is at the lower levels. He addresses two difficulties in choosing the correct lot-sizing technique; namely, the setting of values for the set-up (ordering) cost and the carrying costs for the items considered, and the interactional affects of lot-sizing at different levels.

New concentrates on the estimation of the ordering (set-up) cost and the unit variable cost in a multi-level context. He approaches the problem with an example where several gears are produced from one type of blank. He states that, if gears are produced from batches of gear-blanks which are issued directly from a material store, any batch-costs incurred should be related solely to the manufacturing of the gears and not to any ordering costs for the blanks. In estimating the unit variable cost, on the other hand, the major issue is the concept of added costs, i.e. if a blank has a cost of V_1, and the machining of the blank into gear X adds a variable cost of V_2, then with different arguments one can use either $V=V_1+V_2$ as the unit variable gear cost or only V_2. For further discussion of this issue the reader is referred to (9).

New concludes his paper by presenting a simple lot-sizing model for the two-level case. He presents the model in detail in the Appendix of (9). The model is very elementary and needs to be extended for the cases in which:

- several gears are produced from the same blank
- more than two levels of requirements occur
- the usage of gears is itself non-uniform

Another paper on lot-sizing in MRP Systems is presented by More (8). The author gives a brief introduction to MRP Systems and methods of updating the system (regeneration versus Net Change MRP Systems which has been discussed earlier). Later he concentrates on the least total cost lot-sizing (Part Period Balance) technique. He demonstrates the technique with an example and concludes the paper with the following recommendations that were made in a workshop discussion headed by Plossl and Wight:

1. At the top level, use a fixed order quantity. If requirements change, vary the timing, not the order quantity.
2. At intermediate levels, order one-for-one. This is generally acceptable, since subassemblies' set-up times tend to be very low.
3. At the lower levels of the bill of material use a discrete lot sizing technique such as POQ or Part Period Balance. Since these will be exploded down to a few lower level items, mainly purchased raw materials, the rescheduling problem is minimized.

Note that above recommendations are aimed at cutting down the problem of having substantial changes at lower levels when the top level requirements are changed by a small amount (previously referred as lot-sizing amplification). Recall that a very similar set of recommendations was presented by Steele (16).

Global approaches to MRP Systems:

There are various studies performed with the aim of improving over-all effectiveness of MRP Systems. A very good study is presented by Peterson (13). In this paper he basically discusses some of the unpublicized problem areas in MRP and how they can be better handled to improve the effectiveness of an MRP System. The areas are:

- pegged requirements
- excluding some items from the (MRP) system
- lot-sizing
- lead time determination
- nervous systems
- volume of paper generated by MRP Systems
- Net Change systems

Peterson discusses each area individually. The reader may note that most of the above areas have been discussed in detail. Yet, Peterson's paper serves as a compact guide and provides a very good summary for the reader who wants to learn the problems of MRP Systems without going into details.

Another paper is presented by Bevis (5). He gives a brief historical development of the MRP System within the framework of a medium-size manufacturer of industrial vacuumized power sweepers, scrubbers, etc. When they decide to redesign their requirements planning system they set their objectives as:

- improved customer service based on meeting production plan schedules
- minimum inventory investment at existing production rates
- maximum plant operating efficiency, while maintaining adjustable schedules.

He reports that following six areas were emphasized:

1) inventory accuracy
2) a realistic master schedule
3) bill of material restructuring
4) shop floor control (shop order priorities)
5) valid purchasing priorities (purchase order priorities)
6) continuing employee education.

It is interesting to note that, the first five areas indicated by the above list has been covered by this report (without equal emphasis on inventory accuracy). Bevis (5) discusses each area in reasonable depth but the issues tend to get problem specific rather than general.

So far, we have discussed those papers that fall into one of the four areas mentioned earlier; namely, structuring the bill of material, unplanned demands and rescheduling, lot-sizing and scheduling techniques, and finally those studies that consider the system as a whole, ie. the global approach. There still exists other studies that do not necessarily fall precisely (or directly) into one of these areas.

One such paper is presented by Wilkerson (19). It is concerned with the application of MRP concepts to manpower planning. In a high technology environment manpower planning becomes quite complex. The problem, as cited by the author, becomes one of determining, as closely as possible, requirements for skilled technicians well into the future so that procedures can be implemented in time to acquire the necessary skilled and trained personnel when required. Throughout the paper the author establishes the correspondence between MRP concepts (and techniques) and manpower planning. An important aspect of the approach, as addressed by the author, is that, manpower is not used up like parts or components and therefore requires a slightly different analysis. Manpower should be considered as a certain amount of man-hours which will be used up. Controlling man-hours will make it possible to predict shortages and overages in manpower. Furthermore, if man-hours are not used they are lost, ie. they cannot be carried forward.

Another paper is presented by Sheveley (15). It is concerned with applying MRP techniques in inventory valuation. He approaches the problem in three steps:

1. Finding the inventory necessary to meet the expected sales
2. Determining the number of years the available inventory would support sales
3. Evaluating the inventory based on the number of years supply and its current cost.

The author reports his results by using a simulation model with hypothetical inventory. Basically, the simulation model uses consolidated information from the sales invoice as an estimate of the sales history and the bills of material to establish which lower level components will be needed to meet the sales demands of the finished parts. The author states that results of the model enable management to make a more realistic valuation of its assets and it enables operational managers to recognize erroneous decision rules used for inventory management.

Putnam and Everdell present a paper where the development of MRP Systems are discussed (14). They emphasize the evolution of MRP Systems from earlier planning systems. Yost (20) presents a paper concerned with real-time MRP Systems as opposed to batch-oriented MRP Systems. In previous terminology, "bucketless" MRP Systems is the subject of his paper. The author claims that batch-oriented systems have a diminishing rate of performance as they become more sophisticated, ie. a performance threshold is reached which cannot be passed; and that only real time systems have the capacity for passing this threshold. He provides good examples to show the advantages of using a real time MRP but fails to recognize various drawbacks associated with it.

There is a paper written by the Material Requirements Planning Subcommittee of the American Production and Inventory Control Society (APICS). It is a study guide to assist the candidate in his preparation for taking the MRP examination. The contents of this paper are not within the scope of this report; however, it contains a rich bibliography for the reader who is interested to learn about MRP Systems. The reader is referred to (1).

Finally, an article is presented by Wight (18). It introduces a new concept, namely, Manufacturing Resource Planning (MRP II). The technique is made possible by two things: the computer, and the MRP. It basically consists of combining all the data in a common data base and have every function of the organization (R & D, Finance, Purchasing, Management, Marketing, etc.) interact through this common data base in their own language.

Future Research in MRP Systems:

Berry and Whybark (3) present a paper concerned with future research perspectives in MRP Systems. According to the authors, some promising research directions are:

1. The investigation of formal techniques for the decision making aspects of MRP Systems, eg. in preparing the master schedule, lot-sizing, and in setting safety stocks.
2. The development of systematic methods for structuring bills of material. Such research will facilitate forecasting and master scheduling in MRP Systems, and may contribute to important reductions in the overall data processing effort.
3. The analysis of management problems encountered in installing and operating an MRP System, eg. establishing and updating lead times, determining the period of time during which the master schedules should remain fixed, and determining the cost of the "informal control system" to a company.

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E-24-686

Survey of Selected Material Handling Equipment

Submitted to

Research Triangle Institute

Submitted by

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March 1980

CONVEYORS

A conveyor is a horizontal, inclined or vertical device for moving or transporting bulk materials, packages or objects. A general application principle is to use a conveyor when moving uniform loads continuously from point to point over fixed paths where the primary function is transporting the material. The shape of the object to be moved may be regular, uniform, or irregular. It is best if size is uniform and the weight is uniformly distributed. The rate and speed of the move can be uniform or variable. Fifteen general conveyor types were included in the survey. Of these, six appeared to be potentially applicable to the sheet metal center: belt, roller/wheel, slat, magnetic belt, trolley and power and free conveyors. Additionally, transfer tables, automatic palletizers/depalletizers, and sortation conveyors were included in the survey.

Belt Conveyor

A belt conveyor is an endless fabric, rubber, plastic, leather, or metal belt operated over a suitable drive, tail end and bend terminals and over belt idlers or a slider bed for handling materials, packages, or objects placed directly upon the belt. The top and return runs of the belt may be utilized. They operate on level surfaces, on an incline up to 28 degrees, or downgrade. Belt conveyors supported on flat surfaces typically are used as a carrier of individual objects or as a basis for an assembly line. Belts supported by flat rollers will carry bags, bales, boxes, etc. Metal mesh belts are used for applications subjected to heat, cold, or chemicals. Belt conveyors have high capacity capability which can be easily adjusted. They are versatile, elevate or lower loads, provide continuous flow, and are relatively easy to maintain. Some limitations exist such as the path must be fixed, relatively high initial cost, limited elevating angle, straight line flow between pulleys, and limited capability for horizontal turns. The drive is usually provided by a large pulley or drum. Belts can range in width up to 72 in. Belt speeds range up to 800 feet per minute (fpm). Commonly seen speeds range from 45-90 fpm in 15 fpm increments for fixed speed belts, while variable speed models go from 15-45 fpm. There are potentially many uses for belt conveyors in the sheet metal center. The belt conveyor could be used to move individual parts, bins, tote boxes, or unit loads in almost any size range. Long belt conveyors can serve as temporary storage devices.

Representative Sources of Belt Conveyors

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

FMC Corp.
Material Handling Equipment Div.
724 Lexington Ave.
Homer City, PA 15748

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

Logan Co.
Division of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Metzgar Conveyor Co., Inc.
901 Metzgar Drive, N.W.
Comstock Park, MI 49321

Rapistan, Inc.
825 Rapistan Bldg.
Grand Rapids, MI 49505

Rexnord, Inc.
Material Handling Division
Lebanon Road
Danville, KY 40422

Speedways Conveyors, Inc.
201 Speedways Bldg.
Buffalo, NY 14211

Standard Conveyor Co.
2266 N. Second Street
North St. Paul, MN 55109

Standard Handling Devices, Inc.
P.O. Box 13D
14 Sycamore Ave.
Medford (Boston), MA 02155

TEMCO-Veyor, Thompson Equip.
Machine Co., Inc.
Box 1946
York, PA 17405

Roller Conveyor

A roller conveyor supports the load on a series of rollers, turning on fixed bearings, and mounted between side rails at fixed intervals determined by the size of the object to be carried, which is usually moved manually or by gravity. The live roller conveyor is similar to the gravity roller, except that power is applied to some or all of the rollers to propel the loads. Roller conveyors are similar to belt conveyors except they are better for heavy duty loads. Power is usually applied by a chain on sprockets, cables turning the rollers, or belting underneath that is held up against the rollers at intervals by other rollers or devices. Rollers are usually cylindrical tubing with a bearing on each end. Rollers range from 3/4" to 3-1/2" in diameter with length governed by load. Curved sections are used for turns. The rollers may be tapered for turns, or arranged differentially. Three rollers are required under the load at all times. Rollers may be troughed or formed to conform to the shape of the load. "Standard" roller spacing is 3", 4", 6". Roller conveyor systems are usually inexpensive, easy to install, require minimum maintenance, and have long life. Runs can include switches, spurs, gates, scales, deflectors, upenders, processing and packaging equipment. They can be used for almost any load with a rigid riding surface that will contact at least three rollers, for moves between areas, machines and buildings, storage between work stations, loading and unloading carriers, bases for a handling system, and as an integral segment of a composite handling system. Some limitations are their use is restricted to relatively short distances, frequently require load restraints, normal capacity 70-750 lb. per roller, can be designed to handle 10 tons, best for objects with rigid riding surfaces, distance may be limited unless powered rollers are used to account for lack of gravity movement, and heavy loads on a gravity roller system might accelerate beyond control. The powered roller conveyors can move objects on level runs, up slight grades (up to 10°), or restrain descent on down grades (declines to 17°); curves can be powered, more rugged than belt conveyors, but generally are more expensive than gravity or belt conveyors. Rollers vary in width from 16" to 39" with segments frequently available in 5, 7½, and 10 foot sections.

Wheel Conveyor

A wheel conveyor supports the load on a series of skate-like wheels, mounted on common shafts in a frame or on parallel spaced rails, with the wheels spaced to accommodate the size of the load to be carried. They can be adapted to live, rack, and spiral versions as with the roller conveyor. Characteristics of the wheel conveyor are very similar to the roller conveyor. Objects are typically moved by hand or gravity. Wheels run from 2 in. in diameter and up and are staggered on individual shafts. These are lighter weight construction than roller conveyors, easily portable, less expensive than roller, requires about 50% as much grade as rollers, except when used for storage, easy to set up and put away, and usually have lower maintenance cost. Sections come in 5 ft. and 10 ft. lengths, with the number of wheels per foot determining load capacity, which normally ranges up to 1500 pounds per foot. There must be 6 wheels under the load, with a 1½ - 3 in. pitch per 10 ft. section advisable. Some limitations to consider: best application is for solid, smooth-bottom objects, less load capacity than rollers, not as good for spirals as rollers, usually for less extensive use than rollers, and usually for lighter weight items than rollers.

Representative Sources of Roller and Wheel Conveyors

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

The E. W. Buschman Co.
4429 Clifton Ave.
Cincinnati, OH 45232

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

Logan Co.
Division of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Metzgar Conveyor Co., Inc.
901 Metzgar Drive, N.W.
Comstock Park, MI 49321

Rapistan, Inc.
825 Rapistan Bldg.
Grand Rapids, MI 49505

Rexnord, Inc.
Material Handling Division
Lebanon Road
Danville, KY 40422

Speedways Conveyors, Inc.
201 Speedways Bldg.
Buffalo, NY 14211

Standard Conveyor Co.
2266 N. Second Street
North St. Paul, MN 55109
(Roller Conveyors Only)

Standard Handling Devices, Inc.
Box 13D
14 Sycamore Ave.
Medford (Boston), MA 02155

Versa-Ferguson Conveyor Corps.
28 N. Clark Street
Box 152
Mount Sterling, OH 43143

Slat Conveyor

A slat conveyor employs one or more endless chains to which non-overlapping, non-interlocking, spaced slats are attached. The slats are usually either wood or metal. Slats that are only 1/4"-1/2" apart provide a relatively continuous surface. Typically, these conveyors are sturdy, heavy duty, and have low maintenance cost. Primary uses are for heavy, unit loads (crates, cartons, drums, rolls, bags, etc.), hot materials (castings, forgings, molds), wet materials, and warehousing goods - to and from storage. Maximum speeds range from 50-70 feet per minute. They have relatively expensive initial cost and are not good for small or sticky materials.

Representative Sources of Slat Conveyors

ACCO
Chain Conveyor Div.
12755 E. Nine Mile Rd.
Warren, MI 48089

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

The E. W. Buschman Co.
4429 Clifton Ave.
Cincinnati, OH 45232

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

Logan Co.
Division of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Metzgar Conveyor Co., Inc.
901 Metzgar Dr., N.W.
Comstock Park, MI 49321

Rexnord, Inc.
Material Handling Div.
Lebanon Road
Danville, KY 40422

TEMCO-Veyor, Thompson Equipment Machine Co., Inc.
Box 1946
York, PA 17405

Magnetic Belt Conveyor

The magnetic belt conveyor is a belt conveyor operating over a slider bed containing permanent magnets for handling ferrous metal parts. When space is at a premium and ferrous metal tote boxes or parts are the unit to be moved, then an inclined magnetic belt conveyor could be advantageous. The widths and speeds available for this type of conveyor are comparable to those found in standard belt conveyors. However, the initial costs and maintenance expense are usually higher.

Representative Sources of Magnetic Belt Conveyors

Bunting Magnetics Co.
2100 Estes Ave.
Elk Grove Village, IL 60007

Eriez Magnetics
467 Magnet Dr.
Erie, PA 16512

Metzgar Conveyor Co., Inc.
901 Metzgar Dr., N.W.
Comstock Park, MI 49321

Versa-Ferguson Conveyor Corps.
28 N. Clark Street
Box 152
Mount Sterling, OH 43143

Trolley Conveyor

A trolley conveyor is a series of baskets/carts/trolleys supported from or within an overhead track and connected by an endless propelling medium such as chain, cable or other linkage, with the loads usually suspended from the trolleys.

Following is a more detailed list of characteristics of trolley conveyors. The trolleys run either on flanges of structural tracks or inside rectangular or round tubes. The weight of large loads is generally distributed on either a multiple-wheel trolley or on multiple-trolleys with a load bar between. The load carriers are suspended from trolleys and are usually designed for optimum handling of the object being moved. The propelling medium can be chain, cable, or solid link. The trolleys may use sprocket wheel or caterpillar drive. The trolley conveyor functions in 3 dimensions (horizontal, vertical, incline). The track generally is about 8 or 9 feet above the floor. The track may be elevated for the move, then dip down for access to operator or process. The elevated track is easily routed around most obstructions. This frees floor space and helps minimize interference with other traffic. Also the entire track length may be used since there is no specified return run. These systems are relatively inexpensive to install and relocate with the salvage value remaining high. These systems exhibit low operating and maintenance cost. The path of the track is relatively unlimited in length and direction. The track can follow a rather complicated path since the track path is generally easy to alter, shorten, or lengthen. The trolley conveyor can be used to pace shop floor activity. These systems can be made automatic and/or computer controlled. Loads can easily be automatically switched to or from another conveyor. Some manufacturers offer mountings that allow loads to be hung from floor mounted supports.

The use of trolley conveyors has found wide application. They have been used for moving nearly any material or load, overhead moving storage, intra-plant movement, inter-plant movement, inter-floor movement, recirculating materials, order picking with goods on the conveyor and picker selecting as items go past, and moving objects through continuous processes such as painting, baking, degreasing, etc.

These systems have some limitations. They tend to obstruct overhead space and lighting. Once installed the path is fixed until a change is made requiring some downtime. Application may narrow aisles. You can't always run track to the point desired. The load capacity is limited by the track, trolley, and structural support capacity.

Many of the above applications appear well suited for the sheet metal center.

Representative Sources of Trolley Conveyors

ACCO
Chain Conveyor Div.
12755 E. Nine Mile Rd.
Warren, MI 48089

American Monorail, Inc.
Box 43238
Cleveland, OH 44143

Chain-O-Flex Overhead Conveyor Div.
Washington Kinney Co.
4040 W. Lake St.
Chicago, IL 60624

FMC Corp.
Chain Div.
220 S. Belmont Ave.
Box 346B
Indianapolis, IN 46206

Litton UHS
Unit Handling Systems
7100 Industrial Rd.
Florence, KY 41042

Logan Co.
Div. of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Rapistan, Inc.
825 Rapistan Bldg.
Grand Rapids, MI 49505

Rexnord, Inc.
Material Handling Div.
Lebanon Rd.
Danville, KY 40422

Richards Wilcox Manufacturing Co.
430 Third St.
Aurora, IL 60507

Unibilt Overhead Div.
Jervis B. Webb Co.
Webb Dr.
Farmington Hills, MI 48018

Power and Free Conveyor

Power and free conveyors are a combination of powered trolley conveyors and unpowered monorail-type free conveyors. Two sets of tracks are used, usually suspended one above the other. The upper track carries the powered trolley conveyor, and the lower is the free monorail track. Load-carrying free trolleys are engaged by pushers attached to the powered trolley conveyors. Load trolleys can be switched to and from adjacent unpowered free tracks.

Some more characteristics of the power and free conveyor are: "Free" trolleys can be moved by gravity as well as "pushers" that are supported from the powered trolley conveyor. Interconnections may be manually or automatically controlled. Track switches may divert trolleys from "power" to "free" tracks. Dispatching may be automatically controlled. Gravity "free" tracks may be installed between two "power" tracks for storage. Speeds can be varied from one "power" section to another. These systems can include elevating and lowering units in "free" line, can recirculate loads on all or sections of the system, and can be computer controlled.

Their application can be used for temporary storage of loads between points on machining, assembly, and test lines. Others have been used for load routing. A typical application in automobile assembly plants is for overhead storage for later delivery of loads to floor level. They have been used for integrating production, assembly, and test equipment. They can provide for surge storage against a breakdown in one area.

Like all systems there are limitations. The initial cost of these systems is relatively high. They are costly to re-locate.

Applications to the sheet metal center are probably somewhat limited. These systems are generally applied where large, bulky, not necessarily extremely heavy parts are handled in assembly operations.

Representative Sources of Power and Free Conveyors

ACCO
Chain Conveyor Div.
12755 E. Nine Mile Rd.
Warren, MI 48089

American Monorail, Inc.
Box 43238
Cleveland, OH 44143

FMC Corp.
Chain Div.
220 S. Belmont Ave.
Box 346B
Indianapolis, IN 46206

Litton UHS
Unit Handling Systems
7100 Industrial Rd.
Florence, KY 41042

Logan Co.
Div. of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Rapistan, Inc.
825 Rapistan Bldg.
Grand Rapids, MI 49505

Rexnord, Inc.
Material Handling Div.
Lebanon Rd.
Danville, KY 40422

Richards Wilcox Manufacturing Co.
430 Third St.
Aurora, IL 60507

Unibilt Overhead Div.
Jervis B. Webb Co.
Webb Dr.
Farmington Hills, MI 48018

Transfer Tables

Transfer tables are used to move objects onto or off of a conveyor line or merge one conveyor line into another. There are two types of transfer tables. The ball table consists of a group of ball transfers over which flat-surfaced objects may be moved in any direction. The same objective is achieved with a caster table, substituting casters for ball transfers. Application is often seen in roller, belt, and similar conveyors to facilitate making a right-angle turn or to form one conveyor line to another. The turntable will accomplish the same thing. The turntable consists of a series of mounted rollers or wheels on a surface that is capable of rotating at least 180 degrees.

Representative Sources of Transfer Equipment

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

Automation Devices, Inc.
Automation Park
Box AD
Fairview, PA 16415

Logan Co.
Division of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Rexnord, Inc.
Material Handling Div.
Lebanon Road
Danville, KY 40422

Standard Conveyor Co.
2266 N. Second Street
North St. Paul, MN 55109

Palletizer/Depalletizer

A palletizer is an automatic or semiautomatic machine, consisting of synchronized conveyors and mechanisms to receive objects from a conveyor(s) and place them onto pallets according to a prearranged pattern. A depalletizer is an automatic machine consisting of synchronized conveyors and mechanisms to disassemble a pallet load and discharge objects singly. Palletizer/depalletizer equipment can be used to form unit loads before movement and then to break then down again into their units. Therefore application to the sheet metal center may exist if forming unit loads of tote boxes is feasible. A typical operating speed for palletizing equipment is 20 cases per minute. However, specific case speeds are dependent on the number of cases per layer and the number of layers per load.

Representative Sources of Automatic Palletizers/Depalletizers

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

Columbia Machine, Inc.
Material Handling Div.
107 Grand Blvd.
Vancouver, WA 98661

Litton UHS
Von Gal, Drawer 177
Montgomery, AL 36101

Rexnord, Inc.
Material Handling Div.
Lebanon Road
Danville, KY 40422

Versa-Ferguson Conveyor Corps.
28 N. Clark St.
Box 152
Mount Sterling, OH 43143

Sortation Conveyor

A sortation conveyor is a conveyor which receives mixed unit loads and discharges them to segregated spaces or conveyors in response to an automatic dispatch control. Operator attention is often required to introduce the dispatch signal into a memory system. Alternately, automatic identification systems can be used. Sortation devices can route the proper number of units in the correct sequence to other processes or production operations. You can sort products by size (height, length, width), shape or color. Capacity is up to 50 pounds per foot. Speeds range up to 300 feet per minute.

Representative Sources of Sortation Conveyors

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

Logan Co.
Division of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Rapistan, Inc.
825 Rapistan Bldg.
Grand Rapids, MI 49505

Jervis B. Webb Co.
Webb Drive
Farmington Hills, MI 48018

ROBOTS

The industrial robot is an automated programmable transfer and handling machine - a mechanical manipulator which possesses enough intelligence to make elementary decisions, and the dexterity and flexibility to perform an intricate sequence of different motions without human intervention. The robot is not a simple transfer device, manipulator or "man-extender".

The largest amount of application is found in auto assembly plants. Other industries committed to heavy use of robots are the die casting and investment casting shops. Aerospace and electronic manufacturers are currently areas of intense evaluation and development for robot applications.

Beyond these major areas of application robots have found frequent use in material handling, particularly in machine tending, unit transfer, palletizing, stacking, unstacking, sorting, and packaging. Material handling by robots is a growing area of application.

Rapidly escalating labor costs, OSHA regulations, and a pressing need for greater productivity has increased the interest in robots. For example, in 1980, U.S. robot manufacturers anticipate a 43 percent annual increase in the number of robots installed in U.S. industry.

Robots tend to have the following limitations:

1. Capital for initial purchase, or a long-term commitment for a lease contract.
2. Operation in a restricted space. Robots cannot move freely unless they are mounted for travel on traverse bases, rails or conveyors.
3. Initially there should be a willingness by the appropriate

management level to accept a "new" kind of production technology.

4. Considerable imagination combined with the knowledge that many tasks require adaption to the robot as well as the robot to the task.

Benefits and advantages obtained from intelligent application of robots include the following:

1. Increased productivity - Some companies report productivity increases ranging from 10 to 67 percent.
2. Flexibility - Unlike "hard automation," robots can be retaught and reassigned to many, varied tasks. The robot's program, gripper and tooling can generally be changed quickly and easily.
3. Increased product quality - A robot will perform a programmed task repeatedly, consistently, without the vagaries that occur by hand. This means fewer rejects with less scrap.
4. Improved utilization of capital equipment. Robots can usually work faster than humans allowing for the realization of the full potential of high-speed machines.
5. Fewer injuries - Robots relieve people of heavy lifting jobs, and with some modification can withstand noxious or explosive environments hostile to humans. Robots can also function in environments that would be either too hot or cold for humans.
6. Precision - Robots move their arms and hands with speed and ease, yet can also place grippers and tools with amazing accuracy. Repeatable positioning within $\pm$ 0.008 - inch is common. One of the newer robots claims a repeat accuracy of $\pm$ 0.002 - inch.

7. Resistance to inflation. The use of robots can enable organizations to maintain or even reduce manufacturing costs.
8. Fast teaching and reteaching - It typically takes only a matter of hours to program the tasks for a robot. Programs can be stored on inexpensive magnetic tape cassettes, interchanged, stored, erased and reused.
9. Round-the-clock output. Robots will perform at the same rate for extended periods of time.
10. Reduced inventories, better inventory control.
11. Lower indirect and hidden costs, including longer life from dies and tools, lower energy consumption per part or task, lower average absenteeism in the workforce, and lower costs for OSHA compliance.
12. Improved morale - There is evidence to indicate that people who supervise or work alongside robots take greater pride in their work, and in the progressiveness of their employer. People who have been relieved of dangerous, tiring, boring, unpleasant, and overly demanding jobs often experience a resurgence of pride, dignity and loyalty to their company.
13. Reasonable maintenance - Builders of robots typically provide part kits for their machines, and incorporate standard, off-the-shelf components whenever possible.

Mechanically the robot remains a simple, straightforward apparatus with traditional hydraulic or electric power for motions, and pneumatic or electric power for gripping. However, today the number of options and accessories has been greatly expanded.

Listed below are some of the general types of optional capabilities and components available for robots.

- Point-to-point or continuous-path programming. Some controls have been designed to accept either or both modes on one program.
- Greater varieties of grippers are available, e.g., vacuum, magnetic and mechanical. Mechanicals come in a wide variety of fingers, claws, turning devices, tool holders, etc. Flexibility is the key to match gripper to task.
- Models having capacities ranging from a few ounces to as high as 2000 pounds.
- Numerous varieties of controls, memory, etc: computers, microprocessors, programmable controllers, solid state and relay logic; and air moving-part logic for explosive atmospheres.
- Sensing can be provided by limit switches, proximity switches, photo-cells, heat sensors, magnetic sensors; also by infrared, laser, and standard light beams and by ultrasound. Considerable work is being done to develop practical, economical vision and coordination systems.
- Cassette program storage.
- Program editors permit alterations in programming with no work interruptions.
- Conveyor, rail and X-Y base mountings, to provide extended horizontal travel, either on production floor or overhead; also, special lifters to extend vertical reach.
- Robot models are available with multiple hands on one arm or multiple arms with multiple hands on each.
- Conveyor tracking systems and devices, utilizing computer memory and sensors.
- Models with anywhere from two to seven axes of motion; additional axes can be obtained with special mountings.
- Choice of mountings include stationary on floor, traverse on floor, or from an overhead structure. Many models can work upright vertical,

inverted, horizontal, or at inclined attitudes.

Some robots have become larger and stronger. Others have become smaller and more accurate. For example, bench-top models are now available for the electronics assembly industry.

Robots have been used with great success in assembly, batch manufacturing, die casting, die casting unload and trim, forging and heat treating, foundries, grinding, inspection, investment casting, machine loading and unloading, materials handling and transfer, plastic molding, stamping presses, and welding. Sheet metal handling applications are many. In the area of small parts handling, robots can be used to load and unload tote boxes. They can be used to trim manufactured parts, bend pieces into desired shapes, and transfer of tote boxes.

Points to consider when selecting a robot are axis of motion (horizontal, vertical, traverse, swing), hydraulic power requirements, workholding devices, and utility requirements.

Secondary End of the Arm Motions

	STROKE (MAX.)	VELOCITY PER SEC. (MAX.)	POSITIONING REPEATABILITY
ROTATION	300°	90°	WITHIN .05"
SWEEP	270°	90°	WITHIN .05"
YAW	180°	90°	WITHIN .05"

Load Ratings

Secondary motions at rated velocities (inch pounds);

ROTATE - 5000

SWEEP - 2500

YAW - 2000

The above figures are for the AMF Versatran Automation Systems Mode F Series mechanical units. The characteristics of many other robot devices are similar.

Representative Suppliers of Robots

AMF Versatran Automation Systems
3001 Centreville Road
Herndon, VA 22070

Cincinnati Milacron
Industrial Robot Division
2701 Marburg Ave.
Cincinnati, OH 45209

Coperweld Corp.
Auto-place Division
Troy, MI

The DeVibliss Co.
300 Phillips Ave.
Toledo, OH 43692

FMC
Engineered Systems Division
328 Brockaw Road
Santa Clara, CA 95052

Prab Conveyors, Inc.
Robot Division
5944 E. Kilgore Road
Kalamazoo, MI 49003

Unimation, Inc.
(Headquarters)
Shelter Rock Lane
Danbury, CT 06810

FLOW RACKS

Flow racks facilitate order picking and inventory rotation for storage and handling functions; the racks are designed for loads to "flow" to the unloading position. As one pallet or load is removed from the front of the rack, another load moves forward to fill the empty space. Movement is at a controlled rate by means of live rail, gravity wheel, or roller conveyors. Flow racks permit efficient stock rotation with high density storage.

Flow racks are suited to situations where there are a large number of stock-keeping units and items are picked frequently in small quantities. Several benefits may be obtained in flow rail applications. First, flow rails allow high density storage, eliminating many aisles and thus providing maximum use of available space. Second, inventory control is simplified for either FIFO or LIFO systems. Third, there is less congestion since restocking does not interfere with picking. Also order picking is quicker than for a conventional static shelf system.

Flow rack systems vary from manufacturer to manufacturer. In gravity feed systems, the incline of the racks ranges from .2% to 4%. Some systems have mechanical braking; others have pneumatic controls and programmed spacing between loads. The ease of adjusting racks for new products and sizes also varies; adjustments for some rack systems can be made without tools. Flow rack lifespans may be as much as 20 years.

The type of load handled is the major characteristic which distinguishes most systems. Some flow racks are pallet based; others require special pallets or carriers. Some options which are available include:

1. light duty gravity flow racks designed for small dense cartons or tote pans weighing less than 50 pounds;

2. gravity flow racks designed for the support of soft cardboard boxes;

3. heavy duty racks for use in temperature extremes;

4. racks which use two parallel rails and a four wheel buggy to automatically move the queue forward;

5. racks which use a shuttle car and programmed movement.

Representative Sources of Flow Racks

Alvey, Inc.
9297 Olive Blvd.
St. Louis, MO 63132

A. J. Bayer Co.
Material Handling & Storage
Products Div.
Box 276
Shepherdsville, KY 40165

Conveyor Logic
Box 58, Industrial Park Drive
Dutton, MI 49511

Dexion Inc.
369 Passaic Ave.
Fairfield, NJ 07006

Ermanco, Inc.
6870 Grand Haven Road
Spring Lake, MI 49456

Interlake, Inc.
Commerce Plaza
2015 Spring Road
Oak Brook, IL 60521

The Kingston-Warren Corp.
King-Way Div.
100 Foundry St.
Newfields, NH 03856

Kornylak Corp.
400 Heaton St.
Hamilton, OH 45011

Logan Co.
Div. of A-T-O, Inc.
Box 6107
Louisville, KY 40206

Mallard Mfg. Corp.
101 Mallard Road
Box 309
Sterling, IL 61081

Midland-Ross Corp.
Material Handling Div.
179 N. Michigan Ave.
Kenilworth, NJ 07033

The Paltier Corp.
1701 Kentucky St.
Michigan City, IN 46360

Rollax Handling Systems, Inc.
181 Waverly Place
New York, NY 10014

Speedways Conveyors, Inc.
201 Speedways Bldg.
Buffalo, NY 14211

Storage Systems
Div. of Jervis B. Webb Co.
Webb Dr.
Farmington Hills, MI 48018

BINS AND TOTE BOXES

A tote box is any of a variety of relatively small containers used for consolidating and protecting parts and materials and for in-process handling and storage. Tote boxes may be made of sheet metal, wire, wood, fiberboard, plastic or fiberglass and are available in a wide variety of sizes. Depths range from 2 to 24 inches, widths from 4 to 25 inches, and lengths from 6 to 40 inches.

Tote boxes may have a number of different features. Some materials are resistant to acids, alkalis, oil, grease, moisture, and solvents. Tote boxes may be stackable and/or nestable. Some require shelving while others are self-stacking and "lock" into place when stacked. Custom liners or inserts permit safe handling of odd-shaped or fragile items. Some tote boxes have hand hole grips or handles to aid in handling. Bin-front stacking types permit removal or insertion of contents without disturbing the stack. Weight capacities depend on the material and dimensions of the tote box.

Other types of bins include those for bench assembly units and rotating bin systems.

Since most of the parts in the sheet metal center are less than 2' x 2', tote boxes can be used for storing and handling most of the parts.

Representative Sources of Bins and/or Tote Boxes

Akro-Mils
Box 989
Akron, OH 44309

BQP Industries, Inc.
4747 Ironton Street
Denver, CO 80239

C. R. Daniels, Inc.
3451 Ellicott Center Drive
Ellicott City, MD 21043

Hodge Manufacturing Co., Inc.
55 Fisk Avenue
Springfield, MA 01101

Husky Storage Systems, Inc.
9111 Nevada Avenue
Cleveland, OH 44104

LEWISystems
366 Montgomery Street
Watertown, WI 53094

Lyon Metal Products, Inc.
Box 671
Aurora, IL 60507

NesTier
Material Handling Div.
10605 Chester Road
Cincinnati, OH 45215

Penco Products, Inc.
Brower Ave.
Oaks, PA 19456

Shell Containers, Inc.
Ridge & Race Streets
Ambler, PA 19002

Stackbin Corp.
Box 434
Pawtucket, RI 02862

Stanley-Vidmar
Div. of The Stanley Works
11 Grammes Road
Allentown, PA 18103

SHELVING

There are two basic kinds of shelving available: quick-fastening and bolted. Quick-fastening, or boltless, shelving is slightly more expensive initially, but no tools are needed for assembly. This type of shelving is suited to heavy loads and rapidly changing inventory requirements. Bolted shelving is appropriate when layout requirements are permanent and low initial cost is important.

Both kinds of shelving are available in a wide range of sizes and capacities and with a number of accessories. The most popular height is seven feet, with available heights ranging from six to ten feet. Depths range from twelve to thirty-six inches. The number of shelves per unit and spacing may be almost any combination after allowing three inches for the first shelf off the floor.

The most common type of shelving is the unit consisting of four steel uprights and a number of steel shelves. The shelving unit may be open or closed, and several accessories are available. These include doors, shelf boxes, dividers or partitions, bin fronts, ledge units, and drawer case units.

Greater efficiency and convenience may be obtained through several recent developments in shelving systems. Mezzanine, or double deck shelving, increases the amount of standard height steel shelving that can be placed on a given amount of floor space. High-rise shelving often reaches two to three stories and is appropriate where the same basic storage unit can be used on many shelves. Wide-span shelving with spans of six to eight feet is designed for large and bulky hand-loaded materials. Shelving units which have sloping fronts or sloping shelves with many compartments are suited for storage of small parts or tools.

Also available are side to side rolling shelves and cabinets which are installed on a track. The rolling shelves may be positioned directly in front of stationary shelves for doubled storage area with no aisle. The rolling shelves in front may be shifted to allow access to the rear units.

Other compact filing and storage systems are mounted in rows on mobile carriages; only one transposable aisle is needed. The aisle is created by separating any two carriages.

Representative Sources of Shelving

Akro-Mils
Box 989
Akron, OH 44309

Aurora Steel Products
Div. of White Consolidated Industries
580 S. Lake Street
Aurora, IL 60507

Banner Metals
Div. of Intercole Automation, Inc.
725 S. Adams Road
Suite L-64
Birmingham, MI 48011

Bonus-Bilt, Inc.
1096 Air Way
Glendale, CA 91201

Borroughs Div.
Lear Siegler, Inc.
3002 N. Burdick Street
Kalamazoo, MI 49007

Equipto
207 Cleveland Avenue
Aurora, IL 60507

Hallowell Div.
Standard Pressed Steel Co.
Township Line Road
Hatfield, PA 19440

Husky Storage Systems, Inc.
9111 Nevada Avenue
Cleveland, OH 44104

Inca Metal Products Corp.
1 Inca Pl.
Box 897
Lewisville, TX 75067

InterRoyal Corp.
Deluxe Div.
1 Park Ave.
New York, NY 10016

Lozier Store Fixtures, Inc.
4401 N. 21st Street
Omaha, NE 68110

Lyon Metal Products, Inc.
Box 671
Aurora, IL 60507

Penco Products, Inc.
Brower Avenue
Oaks, PA 19456

Republic Steel Corp.
Industrial Products Div.
1038 Belden Ave. N.E.
Canton, OH 44705

Spacesaver Corp.
1450 Janesville Avenue
Fort Atkinson, WI 53538

Stackbin Corp.
Box 434
Pawtucket, RI 02862

Stanley-Vidmar
Div. of The Stanley Works
11 Grammes Road
Allentown, PA 18103

Tennsco Corp.
Box 606
Dickson, TN 37055

MODULAR DRAWERS

Modular drawer storage uses the concept of standard drawer modules or cabinets to achieve flexibility in the storage of tools and non-bulk inventories. The cabinets have standard widths and depths but vary in heights. Additional cabinets may be added on top or at the side of existing cabinets. A built-in pallet base on most modular cabinets facilitates relocation.

Drawers are available in a wide range of heights and with a variety of accessories such as partitions and dividers, bins, and label holders. Drawers are designed to carry heavy loads with the drawer fully opened.

The key advantage of modular drawer systems over traditional storage methods is in space savings. Depending on the particular application, other advantages might include faster issuance and retrieval of parts and tools and greater security.

Representative Sources of Modular Drawers

Deluxe Lista Corp.
106 Lowland Street
Holliston, MA 01746

Equipto
225 S. Highland Avenue
Aurora, IL 60507

Lyon Metal Products, Inc.
70 Montgomery Street
Aurora, IL 60507

Stanley-Vidmar
11 Grammes Road
Allentown, PA 18103

STACKER CRANE

A device with a rigid upright mass or supports, suspended from a carriage, mounted on an overhead travelling (bridge) crane and fitted with forks or a platform to permit it to place in or retrieve items from racks on either side of the aisle it traverses. Stacker cranes operate in narrow aisles and provide stability at high stacking heights.

Typically, the standard arrangement of the stacker crane utilizes conventional lifting forks mounted on a fork carriage which in turn rises on a mast structure. The mast is mounted on a turntable above to enable it to revolve and place the forks in position to serve both sides of an aisle. The turntable is mounted in a trolley operating across a crane bridge which spans the storage area and enables the fork lift to operate in each of the several aisles between the rows of racks. In place of forks the elevating carriage can be equipped with any of the special attachments available such as rams, roll and box clamps, rotators, etc. In some systems where input/output warrants, the stacker may be dedicated to one aisle, riding on overhead monorail. If the unit travels on rails rather than a crane, transfer devices can be used for aisle transfer. A platform located between the mast structures is equipped with a transfer platform to handle palletized units or tote containers in and out of the racks.

Bridge span is generally between 40' and 70'; however, it can go up to 150'. Typical stacking height is between 25' and 35'. Loads up to 15 tons can be handled. Crane bridge travel speed is between 250 fpm and 350 fpm. Lift speed is limited to 100 fpm.

Representative Sources of Stacker Cranes

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Demag Material Handling Corp.
Box 39245
Cleveland (Solon), OH 44139

Harnischfeger Corp.
4400 W. National Avenue
Milwaukee, WI 53246

Heico, Inc.
S. 14th Avenue
Mendota, IL 61342

AUTOMATED STORAGE/RETRIEVAL SYSTEMS (AS/RS)

AS/R systems play an important role in designing high-rise warehousing systems. They have been shown to be effective for systems that require high volumes of storage and retrieval. A typical AS/RS consists of storage racks, storage/retrieval machines (S/R machines), transfer cars (if any), input-output stations, and a material handling system to interface the AS/RS with its environment.

The basic function of the S/R machine is to store and retrieve loads. Each S/R machine operates in a single aisle with storage racks on either side. The typical S/R machine consists of: a single or double mast frame, a carriage, a shuttle, and a drive and guidance mechanism(s). The frame is designed to add stability to the machine while moving at reasonably high speeds. The lower portion of the frame has wheels which normally run on a single floor rail or two rails. It is guided from above by a support rail that runs along the rack structure. The frame is also used to guide the carriage.

The carriage carries the shuttle which is the mechanism that transfers the load from the S/R machine to the rack opening (or to the input-output station) and vice versa. Typically, an S/R machine has three mechanical drives: the horizontal drive which moves the frame back and forth along the aisle, the vertical drive (hoist drive) which raises and lowers the carriage, and the shuttle drive which transfers the load between the S/R machine and either side of the aisle. The horizontal and vertical drives can both operate at the same time so that the machine moves diagonally in order to reduce travel time.

S/R machines have numerous technical specifications depending upon the particular system under consideration. In general, the system can be considered to be one of the following: unit load automated storage/ retrieval systems (AS/RS), man-on-board AS/RS, and mini load AS/RS.

UNIT LOAD AS/RS

Unit load S/R systems are most commonly used for warehousing finished goods or raw materials in situations where a high volume of material needs to be stored and retrieved. Typically, the loads are palletized or placed in a tote or a container. For light loads the S/R machine capacity generally varies between 300 and 700 pounds, with a lifting height up to 40'. The handling mechanism usually consists of a shuttle table or a mechanical clamp. However, it can also be a vacuum or magnet based mechanism for handling sheet metal and coils.

For heavier loads the S/R machine capacity generally varies between 700 and 8800 pounds, with a lifting height up to 100' and beyond. Typically, the horizontal travel speed is between 250 and 500 fpm, while the vertical travel speed is between 60 and 100 fpm. Shuttle travel is generally around 88 fpm. If the S/R machine needs to be transferred between aisles (which is the case when the number of aisles exceeds the number of S/R machines), then a transfer travel speed of 100 to 160 fpm will apply. (Transfer of the S/R machine is performed by a transfer car located at the end of the aisle.)

Representative Sources of Unit Load AS/RS

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Clark Equipment Co.
Handling Systems Div.
525 N. 24th Street
Battle Creek, MI 49016

Demag Material Handling Corp.
Box 39245
Cleveland (Solon), OH 44139

Harnischfeger Corp.
4400 W. National Avenue
Milwaukee, WI 53246

Hartman Engineering
Div. of Hartman Metal
Fabricators, Inc.
66 School Street
Victor, NY 14564

Heico, Inc.
Stak-O-Matic Systems Div.
S. 14th Avenue
Mendota, IL 61342

Interlake, Inc.
Commerce Plaza
2015 Spring Road
Oak Brook, IL 60521

Kenway, Inc.
210 S. Main St.
Suite 1400
Salt Lake City, UT 84101

Litton UHS
Automove Systems Div.
7875 Convoy Ct.
San Diego, CA 92111

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

Munck Systems, Inc.
Box 9287
Hampton, VA 23369

Jervis B. Webb Co.
Webb Drive
Farmington Hills, MI 48018

MAN-ON-BOARD AS/RS

There exists two ways of storing and retrieving materials in less than unit load quantities: in-aisle and out-of-aisle systems. For in-aisle picking normally the man-on-board S/R machine will be used. The operator picks from shelves, bins or drawers within the storage structure and places the picked items into totes or modules which are then carried by the S/R machine to the end of the aisle for dispatch. The operator's platform may contain auxiliary devices to help him pick heavy items. The machine can be operated manually. However, efficiency can be increased by utilizing automatic controls, including an on-board computer terminal to provide the operator with the necessary information (typically the location of the item and the amount needed). The S/R machine capacity is generally up to 1500 pounds, with a lifting height between 40' and 80'. Vertical and horizontal travel speeds are similar to those of the unit load AS/RS. Some S/R machines will handle up to 4000 pounds, including the operator.

Representative Sources of Man-on-Board AS/RS

Demag Material Handling Corp.
Box 39245
Cleveland (Solon), OH 44139

Hallowell Div.
Standard Pressed Steel Co.
Township Line Road
Hatfield, PA 19440

Harnischfeger Corp.
4400 W. National Avenue
Milwaukee, WI 53246

Hartman Engineering
Div. of Hartman Metal
Fabricators, Inc.
66 School Street
Victor, NY 14564

Heico, Inc.
Stak-O-Matic Systems Div.
S. 14th Avenue
Mendota, IL 61342

Kenway, Inc.
210 S. Main St.
Suite 1400
Salt Lake City, UT 84101

Litton UHS
Man-Rider Div.
1630 Manheim Pike
Lancaster, PA 17601

Munck Systems, Inc.
Box 9287
Hampton, VA 23369

MINI LOAD AS/RS

The mini load AS/RS is appropriate for handling small parts that are stored in containers, tote boxes, etc. Such systems generally provide space savings, better inventory control and reduced inventory levels due to real time inventory control.

The S/R machine of the mini load system is similar in structure to that of the unit load system. However, it is generally equipped with additional or more sophisticated guidance mechanisms in order to meet the requirements imposed by tighter clearances (handling smaller units requires increased accuracy). Load weights generally vary between 300 and 700 pounds. The lifting height is generally between 10' and 40'. Horizontal travel speed is generally 350 fpm, while vertical travel speed is generally between 60 fpm and 80 fpm. The S/R machine can be fully automated by using a dedicated mini computer.

Representative Sources of Mini Load AS/RS

Kenway, Inc.
210 S. Main St.
Suite 1400
Salt Lake City, UT 84101

Supreme Equipment & Systems Corp.
170 53rd Street
Brooklyn, NY 11232

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

CAROUSELS

Basically the carousel concept is a horizontal revolving bin that brings the bin contents to the picker. It consists of a set of carriers where a carrier consists of vertical rows of multi-shelf bins. The drive mechanism rotates the carriers in order to bring the appropriate bin to the picker. The drive mechanism typically is a conveyor with overhead drive or floor mounted (for heavier loads).

Carousels are popular in use for order picking, progressive assembly, production kitting, staging, sorting, test accumulation, and maintenance stores. The number of carriers will generally vary between 20 and 70 carriers. Carriers can handle up to 5000 pounds and have a depth of 12" to 22", a width of 3'8" to 5'4", and a height of 6' to 10'. The carousel speed is usually 60 to 80 fpm. The rated capacity of a carousel is dependent upon the length, bin size, load distribution, usage factor, and the desired speed. They can handle units up to 125' long. Furthermore, special bin and shelf designs are also made available.

Automated storage/retrieval carousels have increased the efficiency of the carousel system. In such systems the number of bins can vary between 20 and 70 bins, with average retrieval time of 8 secs. to 30 secs., respectively. One such system is the CEASARS (Clay's Express Automated Storage and Retrieval System). The CEASARS consists of a multiple level of carousel systems where the retrieval is performed in an automated fashion.

Representative Sources of Carousels

Saratoga Conveyor Corp.
Box 20675
Atlanta, GA 30320

White Machine Co., Inc.
50 Boright Avenue
Kenilworth, NJ 07033

DEEP LANE STORAGE SYSTEMS

A deep lane storage system is similar to a unit load AS/RS with the exception that a single S/R machine handles multiple pallet depths on both sides of the aisle, thereby saving crane aisle space. Such systems also enable order picking to be combined with storage in order to increase efficiency. However, they require a slightly different rack structure and a special purpose vehicle to interface the rack opening with the S/R machine. Such a vehicle is typically a moving platform that carries the load into the lane, senses proper load location, deposits load and returns to cube face for next load. On first-in first-out operations, the vehicle takes the load at the far end of the lane, and carries it out the far end of the lane for retrieval. On last-in, first-out operations, the vehicle stores and retrieves from one face of the cube.

The S/R machine is typically capable of handling loads up to 4000 lbs. The horizontal and vertical speed of the S/R machine can generally go up to 400 fpm and 90 fpm, respectively. The vehicle that interfaces the rack opening with the S/R machine generally weighs around 850 lbs. It has a load capacity of (up to) 4000 lbs. and a horizontal speed up to 120 fpm. It typically measures between 34" and 43", and 44" and 52" in width and length, respectively; and 7" in height.

Representative Sources of Deep Lane Storage Systems

ACCO
Integrated Handling Systems Div.
Box 460
Frederick, MD 21701

Interlake, Inc.
Commerce Plaza
2015 Spring Road
Oak Brook, IL 60521

Litton UHS
Unit Handling Systems
7100 Industrial Road
Florence, KY 41042

SUBCONTRACTOR Georgia Inst. of Technology — Research Triangle Institute — Subcontract 44U-1683 — Prime F33615-78-C-5139

Initial Date 6/14/79
Revision Date 3/24/80

Task		May 1979	June	July	Aug	Sept	Oct	Nov	Dec	Jan 1980	Feb	Mar	Apr	May	June	July	Aug	Total
13	Labor Hours			90	90	90	125	25	25	20	15	15	10					505
	DL* $			2,160	2,160	2,160	3,000	600	600	480	360	360	240					12,120
	ODC** $			0	0	380	0	144	28	247	0	0	0					419
14	Labor Hours						150	100	50									300
	DL* $						3,600	3,400	1,200									7,200
	ODC** $						0	0	0									0
15	Labor Hours						46	196	145	115	100	28						630
	DL* $						1,102	4,704	3,482	2,760	2,400	672						15,120
	ODC** $						0	0	0	0	0	0						0
16	Labor Hours									159	179	62	50					450
	DL* $									3,819	4,299	1,488	1,200					10,800
	ODC** $									0	0	0	0					0
17	Labor Hours											189	293	353				835
	DL* $											4,540	7,060	8,500				20,100
	ODC** $											0	0	0				0
All Tasks	Labor Hours			90	90	90	321	321	220	294	294	294	353	353				2,720
	DL* $			2,160	2,160	2,160	7,702	7,702	5,282	7,059	7,059	7,060	8,500	8,500				65,344
	ODC** $			0	0	380	0	144	28	247	0	0	0	0				799
TOTAL COSTS				2,160	2,160	2,540	7,702	7,846	5,310	7,306	7,059	7,060	8,500	8,500				66,143
TOTAL CUMULATIVE COST***				2,160	4,320	6,860	14,562	22,408	27,718	35,024	42,083	49,143	57,643	66,143				66,143

* Direct Labor (Including Overhead & G & A Share)
** Other Direct Costs (Including G & A Share)

Project Leader Signature John A. White

MONTHLY WORK SHEET

Month April 1980 Date May 9, 1980

Subcontractor Georgia Tech

Task	Monthly Performance Data (Not Cumulative to Date)*				
	Actual Hours	Actual Labor $	Actual ODC** $	Budget Change*** Hours	Budget Change*** $
13	153	3684	---	143	3448
14	50	1204	---	50	1204
15	50	1204	---	50	1204
16	100	2408	---	50	1204
17	---	---	---	(293)	(7060)

* Data is monthly and not cumulative to date
** Other direct costs
*** Note any revisions of original budge sheet for this month, leave blank if there are none

SUBCONTRACTOR Georgia Tech Research Triangle Institute Initial Date

E-24-686 JAW

SCHOOL OF INDUSTRIAL AND SYSTEMS ENGINEERING

Atlanta, Georgia 30332 (404) 894-2300

April 1, 1980

Dr. David L. Kelly
Operations Analysis Division
Research Triangle Institute
P.O. Box 12194
Research Triangle Park, NC 27709

Dear Dave:

Per our telephone conversation of March 19, enclosed is an itemized listing of the charges to the ICAM Project. Any discrepancies in amounts invoiced in a month and the amounts shown on the enclosure are due to internal delays in our accounting system.

Your letter of March 21 suggested Georgia Tech either was (1) transferring charges to the ICAM program that were in fact not legitimate ICAM expenditures or was (2) planning to substantially accelerate our activity over the time remaining on the project. Neither situation exists! We are simply making charges against the account based on work performed and consistent with the May termination date in our contract.

Dave, I regret that the situation has degenerated to the point that it has. Let me assure you that you need not question the integrity of our staff and/or accounting office. The only changes that have occurred in our budgeting, as a result of your request to delete Task 17, is to reduce the charges - not increase them.

By April 10 you will be sent the reports you requested concerning our status on the ICAM Program. In the meantime, I hope the enclosed information answers the questions you raised in your letter of March 27, 1980.

Very truly yours,

John A. White, Ph.D.
Professor

JAW:vld

enclosure

cc: Dr. M. E. Thomas

MONTHLY CHARGES TO ICAM PROJECT

	Personal Services			Retirement	Overhead	Total
	(A)	(B)	(C)	(A&B)	(A,B,C)	
Month	J. White	Secy.	GRA's			
6/79	-0-	-0-	-0-	-0-	-0-	-0-
7/79	836.83	321.50	-0-	121.74	880.33	2,160.40
8/79	836.83	321.50	-0-	121.74	880.33	2,160.40
9/79	836.83	321.50	-0-	121.74	880.33	2,160.40
10/79	2,510.50	321.50	1,375.00(2)	297.64	3,197.32	7,701.96
11/79	2,510.50	321.50	1,375.00(2)	297.64	3,197.32	7,701.96
12/79	2,510.50	321.50	-0-	297.64	2,152.32	5,281.96
1/80	2,117.49	330.20	1,416.67(3)	257.25	2,936.91	7,058.52
2/80	2,117.49	330.20	1,416.67(3)	257.25	2,936.91	7,058.52
3/80	2,117.49	330.20	1,416.67(3)	257.25	2,936.91	7,058.52
4/80	2,117.49	330.20	2,125.00(3)	257.25	3,670.75	8,500.69
5/80	2,117.49	330.20	2,125.00(3)	257.25	3,670.75	8,500.69
Total	20,629.44	3,580.00	11,250.01	2,544.39	27,340.18	65,344.02

Non-Personal Services				Total
Month	M & S	Computer	Travel	
6/79	-0-	-0-	-0-	-0-
7/79	-0-	-0-	-0-	-0-
8/79	-0-	-0-	-0-	-0-
9/79	-0-	-0-	379.63	379.63
10/79	-0-	-0-	-0-	-0-
11/79	144.34	-0-	-0-	144.34
12/79	27.60	-0-	-0-	27.60
1/80	58.36	-0-	188.60	246.96
2/80	-0-	-0-	-0-	-0-
3/80	-0-	-0-	-0-	-0-
4/80	-0-	-0-	-0-	-0-
5/80	-0-	-0-	-0-	-0-
Total	230.30	-0-	568.23	798.53

SUMMARY

Month	Personal Services	Retirement	Overhead	Non-Personal Services	Total
6/79	-0-	-0-	-0-	-0-	-0-
7/79	1,158.33	121.74	880.33	-0-	2,160.40
8/79	1,158.33	121.74	880.33	-0-	2,160.40
9/79	1,158.33	121.74	880.33	379.63	2,540.03
10/79	4,207.00	297.64	3,197.32	-0-	7,701.96
11/79	4,207.00	297.64	3,197.32	144.34	7,846.30
12/79	2,832.00	297.64	2,152.32	27.60	5,309.56
1/80	3,864.36	257.25	2,936.91	246.96	7,305.48
2/80	3,864.36	257.25	2,936.91	-0-	7,058.52
3/80	3,864.36	257.25	2,936.91	-0-	7,058.52
4/80	4,572.69	257.25	3,670.75	-0-	8,500.69
5/80	4,572.69	257.25	3,670.75	-0-	8,500.69
Total	35,459.45	2,544.39	27,340.18	798.53	66,142.55

	Budgeted	Encumbered/ Expended	Balance
Phase I	46,009	40,821	5,188
Phase II	66,400	66,143	257
			5,445